Pink Bollworm Control in the Western United States

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Edited by H. M. Graham

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ABSTRACT

The pink bollworm is a serious pest of cotton in the desert areas of the Western United States, causing losses in yield and quality of lint and seed. The insect may cause other adverse effects, such as increasing contamination of the seed with the carcinogen aflatoxin produced by a mold; increasing production costs by requiring applications of insecticides to control infestations, which may also create outbreaks of secondary pests by destroying naturally occurring parasites and predators; and, in some instances, the insecticide applications may present a direct hazard to nearby humans and wildlife.

Measures taken to reduce populations of pink bollworm and the reliance on pesticides for their control include (1) reducing the number of moths infesting cotton in the spring, (2) reducing the number of larvae entering the overwintering stage, and (3) reducing the number of larvae surviving the winter.

This publication is a semitechnical review of the results of research into the cultural control of the pink bollworm. Until now, these results were scattered among a number of smaller publications. This publication will be an important source for extension workers, consultants, and others involved in controlling pink bollworms.

KEYWORDS: Biological control, cotton cultivars, entomopathogens, entomophagous insects, pink bollworm control, sex pheromones, sterile insect release.

CONTENTS

PINK BOLLWORM CONTROL IN THE WESTERN UNITED STATES

SUMMARY

The pink bollworm is a serious pest of cotton in the desert areas of the Western United States, causing losses in yield and quality of lint and seeds. The insect may cause other adverse effects, such as increasing contamination of the seed with the carcinogen aflatoxin produced by a mold; increasing production costs by requiring applications of insecticides for the control of infestations, which may also create outbreaks of secondary pests by destroying naturally occurring parasites and predators; and, in some instances, the insecticide applications may present a direct hazard to nearby humans and wildlife.

Some measures can be used to reduce the populations of the pink bollworm and the reliance on pesticides for its control. These measures are directed at: (1) reducing the numbers of moths infesting cotton in the spring, (2) reducing the numbers of larvae entering the overwintering stage, and (3) reducing the number of overwintering larvae surviving the winter.

Avoidance of early planting can reduce the numbers of moths that survive to infest cotton in the spring. If planting is too late, however, it can result in yield losses, increased damage by late season infestations of insects such as the tobacco budworm, and increased proportions of the pink bollworm and other pests entering the overwintering stage.

The most practical approach to reducing pink bollworm populations is to plant when optimal conditions for seed germination occur, produce a heavy boll set before the extreme summer heat reduces fruiting, and terminate fruiting earlier than it is now normally accomplished. At present, early termination of fruiting is limited to cessation of irrigation and to early maturing varieties. An irrigation termination of August 1 at Yuma, Ariz., reduced overwintering pink bollworm populations with no reduction in yield compared with later irrigation termination dates. This date would have to be altered for other locations, depending on soil type and other factors. Not only does the production of an early cotton crop decrease overwintering pink bollworm populations, it also may result in increased quality of the cotton by avoiding insect damage, boll rot, and storm damage that can occur in later cotton.

Plant growth regulators have been used effectively to terminate cotton fruiting. These may have some advantages over irrigation termination, but none is registered for this use on cotton as yet.

Significant mortality of overwintering pink bollworm larvae can be achieved by using a sequence of cultural measures during the winter. These include shredding cotton stalks after harvest, disking and plowing debris in the fields, applying winter irrigation, or growing a winter crop such as barley.

While use of these cultural control measures will reduce the number of insecticide applications needed to prevent losses from pink bollworm infestations, at times they will be needed. Applications should be made only when infestations exceed recommended treatment levels, and only recommended materials and rates should be used.

A number of other noninsecticidal methods for suppressing pink bollworm populations are at various stages of research and development. These include resistant cottons (including nectariless types), sex pheromones, release of sterile pink bollworm moths, and biological control agents; however, varying degrees of development and evaluation of these measures are needed before recommendations can be given for the general use of any one of them.

INTRODUCTION

By H. M. Graham[1]

The pink bollworm, *Pectinophora gossypiella* (Saunders), has been a significant pest of cotton in the United States since the first persistent infestation was established in the area of Presidio, Tex., in 1918. The pest presently infests cotton from Texas to California, with an isolated infestation in wild cotton in southern Florida. It is especially damaging in the cotton growing area of central and western Arizona and southern California, where the infestation has persisted since 1965. Large quantities of chemical insecticides are used annually for its control. At present, the insect has not become established in the cotton producing areas of the San Joaquin Valley of California, although native moths have been trapped there since 1967.

Infestations by pink bollworms can cause severe losses in yield and quality of cotton if allowed to go unchecked. One of the commonest methods used to control the pink bollworm is by applications of insecticides; however, these applications, by destroying predators and parasites in the fields, can lead to outbreaks of secondary pests such as the bollworm, tobacco budworm, and cotton leafperforator, as well as the development of resistance to the insecticides by the pink bollworm.

A number of noninsecticidal methods for controlling the pinl bollworm have been developed and can be very effective, especially when integrated into a control system. A publication prepared by members of the S-37 Regional Research Project summarized cultural control measures that were effective against the pink bollworm, chiefly in Texas.[2] The extensive use of these and other control measures has relegated the pink bollworm to the status of a minor pest in that area. Noble[3] brought together a summary of the research that had been carried out on the pink bollworm from 1918 to 1968 that included practical control methods as well as methods still in the development stage that showed promise in suppressing the pest.

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[2]Martin, D. F., and Lewis, R. D. (eds.). A summary of recent research basic to the cultural control of the pink bollworm. Texas Agricultural Experiment Station. Miscellaneous Publication No. 579, 28 p. 1962.

[3]Noble, L. W. Fifty years of research on the pink bollworm in the United States. U.S. Department of Agriculture, Agriculture Handbook No. 357, 62 p. 1969.

This publication is intended to update the information in the above publications, with special emphasis on methods for controlling the pest under the conditions in California and Arizona. It will consolidate the results of various studies published elsewhere and provide some guidelines to be used by growers for suppressing populations of the pink bollworm. If the information in this publication is used, cotton producers in areas subject to damage by the pink bollworm should be able to produce their crops more economically and with less reliance on chemical insecticides. If some alternative system of pink bollworm control is not used to reduce the quantity of pesticides currently applied for control of the pest, we feel the cotton producers in these areas are destined to have much more severe problems with the pink bollworm and secondary pests.

PINK BOLLWORM: BIOLOGY, SEASONAL HISTORY, DISPERSAL, AND DAMAGE

By H. M. Graham[1]

BIOLOGY

While the pink bollworm is primarily a pest of cotton, Noble (*1969*)[2] lists 70 species of plants in seven families as alternate hosts. Besides cotton, the only other cultivated host of some importance in the United States is okra. Although okra is a good host for the pink bollworm, the pest is of little importance on it because the pods are picked when they are 1 to 3 days old, and the pink bollworms are either in the egg stage or the larvae are too small to be of significance. Pink bollworm larvae in the harvested young pods, however, can complete their development if the pods are not utilized or disposed of in a manner that destroys the larvae (Graham and Stephenson *1966*). Okra fields that are abandoned after harvesting is finished or are grown for seed production can provide a reservoir of pink bollworms.

Noble (*1969*) provides a general discussion of the biology of the pink bollworm. The eggs are small, elongate, and whitish when first laid, turning reddish orange just before hatching. The moths deposit eggs at night on the cotton plants, preferring squares, stems, and terminals early in the season. When bolls are present in mid- and late season, a high proportion of the eggs is laid around the calyx and base of the bolls.

The eggs hatch in about 4 days in the summer, but take longer to hatch in cooler temperatures. Newly hatched larvae move about the plants and enter squares or bolls, where they spend the remainder of the larvae period--about 2 weeks in the summer. The larvae generally molt three times during this period. Squares over 10 days old are usually attacked; younger ones are frequently shed shortly after being infested. The larva feeds on anthers, and its development often corresponds to that of the square, so that when the bloom opens the larva is in its final stage. These larvae tie the petals together with silk, producing a "rosetted" bloom that enables detection of pink bollworm infestation at this stage. Occasionally, these larvae will feed on the small boll at the base of the bloom, but most drop to the ground where they make a loose cocoon in the litter and pupate.

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 8.

Pink bollworm larvae usually infest semifirm bolls 10 to 20 days of age. They bore through the carpel wall to the interior of the boll leaving a minute entrance hole, which usually cannot be seen with the unaided eye. The larvae produce warts or characteristic mines on the interior surface of the carpel wall that can be used to determine the degree of infestation. Once inside the boll, the larva finds a cottonseed and feeds within it, occasionally feeding on a second seed or more during its development. After completing its larval period, it moves back to the carpel wall, cuts a hole about one-sixteenth of an inch in diameter and crawls out to pupate beneath the plants.

As daylengths shorten in August and September, increasing proportions of the pink bollworm larvae fail to enter the pupal stage when mature and remain as diapausing, or resting, larvae through the winter. These proportions show a very sharp increase in mid- to late September. Many of these diapausing larvae will remain within the cottonseed; however, varying portions (about 50 percent) leave the bolls and form very tightly woven cocoons in the litter on the soil surface or in the upper parts of the soil. These overwintering larvae are vulnerable to cultural practices such as shredding, plowing, and irrigation.

Diapausing larvae remain quiescent until temperatures warm in the spring and days lengthen. Then they form pupae. Moisture, such as irrigation, then stimulates the transformation to pupae. Not all the larvae will pupate at the same time. Pupation and emergence of the moths from these pupae usually extend over 4 to 5 months, although peak emergence covers 1 to 2 months. In rare instances, larvae have remained in diapause up to 2 years.

After emerging from the pupa, a pink bollworm moth takes 2 days to become sexually mature. Mating takes place in the upper parts of the plants after midnight in the summer. The female emits an attractant, or sex pheromone, to attract males for mating. The day following mating, the female will begin laying eggs. The moths may mate more than once during their lives, which last 10 to 14 days in the summer. They require food in the form of nectar for maximum reproduction and longevity. Females may lay 100 to 200 eggs during their lives.

SEASONAL HISTORY

It is apparent from the preceding description of the biology of the pink bollworm that the seasonal history of the insect is as follows: In the spring, the overwintering larvae pupate and moths emerge and mate. This emergence usually starts before cotton is squaring; and, if no fruiting host plant is available, these adults will die without reproducing (Bariola *1978*). When squaring cotton is present, the females will lay their eggs on it, and larvae develop in the squares. These first-generation larvae will mature about the same time the first blooms appear or slightly earlier (Slosser and Watson *1972*).

The second generation larvae will be in both squares and bolls, whereas later generations are mainly in bolls until the cotton crop matures and squares again become the predominant fruiting form. Each generation requires about 1 month during the summer. The number of generations will depend on the length of the growing season and may range from three to six, with populations frequently increasing at a rate of five- to tenfold per generation, although the population

tends to decline in the first generation. At Mesa, Ariz., Slosser and Watson (*1972*) found the first reproduction by overwintered moths in the second week of June, with the second generation in late June and early July. The latter generation was produced by both overwintered and current-season moths. Other peaks of larvae occurred in late July, late August, and late September. Damaging populations of pink bollworms are not usually found until midseason, after two or three generations. Overwintering larvae become abundant in late September and October and remain in this diapausing state until spring.

DISPERSAL

Upon emerging from diapausing larvae in the spring, pink bollworm moths appear to fly about randomly until fruiting host plants are available. After this time, most will be found in the vicinity of the cottonfields. There is also some degree of interfield movement of moths when high populations are reached in the latter part of the season and the cotton is beginning to mature.

Pink bollworm moths are capable of moving long distances, especially when breeding sites are scarce, as early in the season or after cotton begins to mature. Isolated plantings of cotton in California and Texas have become infested when the nearest source of pink bollworms was up to 65 miles away (Bariola et al. *1973*, McDonald and Loftin *1935*). Studies in California on trapping pink bollworm moths in the Mojave Desert indicate moths from the Coachella Valley area are traveling over 100 miles to the San Joaquin Valley (Stern *1979*). Records of catches of moths in the Mojave Desert indicate that tropical storm fronts may carry large numbers of pink bollworm moths from infested areas. Other studies have shown pink bollworm moths in the air at altitudes of 3,000 ft (Glick *1939*).

Diapausing larvae in cottonseed are also a source of spread of this insect. These may be spread in seed cotton attached to cottonpickers and trailers, by floodwaters, or by bulk shipments of cottonseed.

DAMAGE BY PINK BOLLWORMS

Feeding of pink bollworm larvae in cotton bolls results in losses in yield and quality of the seed and lint. Studies have shown severe infestations can reduce yields 50 to 80 percent compared with those in plots treated with insecticides (Noble *1969*, Henneberry et al. *1978*). While the damage from an infestation may be directly related to the degree of infestation, the amount of damage caused by a given infestation of pink bollworm is affected by other factors, such as the growth stage of the crop, rainfall, and humidity. Boll damage is greater as the number of larvae per boll increases. Greater damage results in humid areas or in arid regions during periods of high humidity after rains. Under these conditions, fungi may enter the exit holes and cause boll rots. One of these fungi, *Aspergillus flavus* Link, produces aflatoxin, a potent carcinogen, in the bolls and may contaminate the seed. From this source, it may enter the human food supply (Ashworth et al. *1971*, Russell et al. *1976*, Henneberry et al. *1978*).

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PINK BOLLWORM CONTROL: POTENTIAL OF COTTON CROP MANAGEMENT TO SELECTIVELY LIMIT HOST AVAILABILITY

By T. J. Henneberry, L. A. Bariola, and D. L. Kittock[1]

INTRODUCTION

Two critical periods in the seasonal cycle of the pink bollworm, *Pectinophora gossypiella* (Saunders), having significant impact on the development of larval infestations in cotton, *Gossypium* spp., during the growing season are: (1) emergence and subsequent survival of moths in the spring, and (2) numbers and survival of overwintering larvae. The two phenomena, of course, are closely related. Pink bollworm moth emergence in Arizona, as reported by Wene et al. (*1961*, *1965*),[2] begins in late March and continues into late July and early August. Some early moth emergence occurs before cotton fruiting forms are available ("suicidal" emergence), but the distribution of emerging moths appears to insure numbers of insects to initiate infestations in cotton planted at the normal time. For example, Fye (*1979*) reported that pink bollworm moth emergence in Arizona from prepupae in free cocoons generally occurred earlier (May to early June) than from prepupae in bolls. Moth emergence from bolls occurred from late May to late August and early September with one major peak of emergence in June and a second occurring in late July and early August. These data suggest that although delay of early square infestations by delayed planting may have potential, some pink bollworm moths from overwintered larvae emerge when susceptible bolls are first available in mid- to late June and later. The possibility, however, has been explored that cotton planted late might escape exposure of early season fruiting forms to significant numbers of moths and thus delay or escape infestation.

As many as five generations of the insect may develop during the cotton growing season (Slosser and Watson *1972*). Heavy reliance on insecticides accomplishes field-by-field control during the growing season. Late in the growing season (mid- to late September), insecticide applications are customarily terminated, and, subsequently, large numbers of diapausing larvae are found in

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 19.

late-season bolls. Considerable research attention, therefore, has also been focused on developing late-season cultural control strategies to prevent the development or to induce high mortality (Noble *1969*) of the overwintering generation. The purpose of this paper will be to consider the potential impact of cotton crop management in the first two of these areas on pink bollworm populations, whereas the effectiveness of methods to increase mortality of overwintering pink bollworm larvae will be considered in another paper in this series.

ESCAPE OF INFESTATIONS BY DELAY OF PLANTING DATE

Percentages are shown in figure 1 of total pink bollworm moth emergence from overwintering diapausing larvae in Arizona and southern California on a monthly basis from March through August. The data were calculated from the published reports of Wene et al. (*1961*, *1965*) and Watson and Larsen (*1968*) for Phoenix, Ariz.; Slosser and Watson (*1972*) for Tucson, Ariz.; Bariola (unpublished data) for Marana and Parker, Ariz. (*1973* and *1974*, respectively); and Rice and Reynolds (*1971*) and Bariola (unpublished data) for Meloland, Calif. The data of Sevacherian et al. (*1977*) appear similar. Moth emergence data for all these locations (lower elevation deserts) except Safford, Ariz. (at a higher elevation) are similar and means are shown in figure 1. (Safford data are plotted separately in fig. 1).

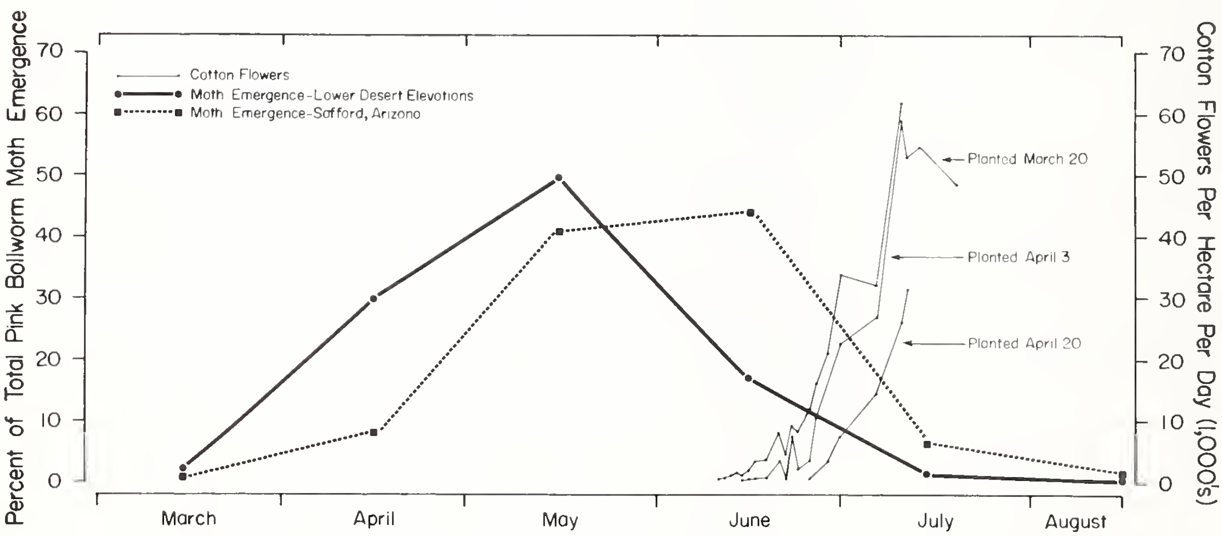

Figure 1.--Percentage of pink bollworm moth emergence on a monthly basis and 'Deltapine 61' cotton flowers per hectare per day. Mean values of total data are from Wene et al. *1965*, Watson and Larsen *1968* for Phoenix, Ariz.; Slosser and Watson *1972* for Tucson, Ariz.; Bariola, unpublished data for Parker, Ariz.; Rice and Reynolds *1971* for Meloland, Calif.; and Bariola, unpublished data for Meloland, Calif. Calculated values are from data of Wene et al. *1965* for Safford, Ariz.

In the lower elevation deserts, approximately 95 percent of the moths produced from overwintering larvae emerged from mid-March through mid-June (fig. 1). The ranges of moth emergence for all locations (except Safford, Ariz.) were

for March, 0 to 5.4 percent; April, 0.6 to 56.4 percent; May, 32.7 to 83.1 percent; June, 12.1 to 31.7 percent; July, 0 to 7.3 percent; and August, 0 to 0.2 percent. Cotton fruiting forms (squares) are present in Arizona and southern California cotton between mid-May and early June for cotton planted between March 20 and April 20 (Kittock, unpublished data).

Although pink bollworm moths from overwintered larvae survive relatively long periods (Fenton and Owens *1953*) and longevity is increased dramatically at low temperatures (Butler and Watson *1980*), Bariola (*1978*) found that moths emerging as late as 3 days before squares were present on cotton produced few progeny and could be considered suicidal. Chapman et al. (*1960*) reported similar findings. Bariola (*1978*) reported that when only squares were available on cotton plants, the rate of pink bollworm population increase was only about 0.5 fold. A number of authors have estimated suicidal emergence to range from 57 to 86 percent in the desert valley growing areas of Arizona and California and from 28 to 80 percent at the higher elevation of Safford (table 1).

Table 1.--*Percent pink bollworm moth "suicidal" emergence in cotton plots as reported by various authors*

Reference	Year of test	Location	Suicidal emergence
			Percent
Wene et al. (*1965*)	1958	Safford, Ariz.	80
	1960	--do--	57
	1961	--do--	37
	1962	--do--	59
	1963	--do--	28
	1964	--do--	37
	1959	Phoenix, Ariz.	84
	1960	--do--	86
Watson and Larsen (*1968*)	1967	--do--	75
Watson et al. (*1970*)	1967	--do--	62
Rice and Reynolds (*1971*)	1969	Meloland, Calif.	57
	1970	--do--	83
Slosser and Watson (*1972*)	1967	Tucson, Ariz.	75
Bariola et al. (*1976*)	1973	Marana, Ariz.	72

Thus, the potential exists to reduce significantly early season infestations if cotton can be planted late enough to delay the occurrence of fruiting forms. For example, Adkisson et al. (*1962*) reviewed cotton planting dates as a factor in pink bollworm control in Texas. The authors assumed 70 and 60 days, respectively, for square formation in plants seeded early (before soil temperature reached 60°F) and late (after soil temperature reached 60°F). Suicidal moth emergence of 99 percent was estimated at Weslaco irrespective of early (Feb. 1) or late (Mar. 15) planting dates. At College Station in early (Mar. 20) and

late (Apr. 15) plantings and at Waco in early (Apr. 1) and late (May 1) plantings, suicidal emergence was 55 and 88 percent, and 78 and 90 percent, respectively. Based on these data, the authors calculated that pink bollworm populations could be reduced theoretically two- to almost fourfold by planting cotton at the optimum time.

The high overwintering populations that often exist in Arizona and California (table 2), however, appear to ensure adequate numbers in most cases to initiate infestations even though high percentages emerge suicidally. Extremely late planting may be required to escape significant numbers of emerging pink bollworms and may entail the risks of reduced cotton yields and increased overwintering larval populations. For example, Kittock (unpublished data) found that cotton flowering was delayed approximately 4 and 15 days, respectively, when seeds were planted April 3 and April 20 as compared to those planted March 20 (fig. 1). First flowers occurred on June 10, June 15, and June 25, respectively, for cotton planted March 20, April 3, and April 20. Therefore, squares

Table 2.--*Spring pink bollworm moth emergence in various cotton-growing areas in California and Arizona*

Reference	Moth emergence per hectare				Variation a result of:
	Location	Year	Average	Range	
Watson and Larsen (*1968*)	Phoenix, Ariz.	1967	9,665	2,223-18,525	Cultural practices.
Watson et al. (*1970*)	--do--	1967	3,853	2,964- 5,681	Stalk shredding.
	Mesa, Ariz.	1968	81,922	80,275-83,980	Do.
	Safford, Ariz.	1968	679	618-741	Do.
Rice and Reynolds (*1971*)	Meloland, Calif.	1969	4,817	---	---
	--do--	1970	28,148	---	---
Watson et al. (*1974*)	Mesa, Ariz.	1968	22,677	9,808-42,272	Plowdown date.
	--do--	1969	3,705	395- 8,596	Do.
Bariola et al. (*1976*)	Marana, Ariz.	1973	63,101	50,400-85,000	Chemical termination.
	Parker, Ariz.	1974	20,750	13,301-27,400	Do.
Unpublished data	Meloland, Calif.	1975	10,806	4,940-16,673	Do.

were available in early June (about 21 days prior to flowering) as host material for initiation of pink bollworm infestations, even in plants from the latest planting date (Apr. 20) because substantial numbers of moths were still emerging. The possibility of taking advantage of delayed planting to avoid early infestation should not be completely dismissed. The relationship between the number of moths emerging in the spring per unit area, magnitude of the early season infestation, and the economic threshold of infestation is not well known. Graham et al. (*1962*), however, indicated that 8,000 pink bollworms per acre were required to reach 20 percent infested bolls. From reported moth emergence data (table 2), some benefit of reduced pink bollworm infestations may be attained by delayed planting if an acceptable compromise can be achieved without reducing yield or increasing late infestations.

The possibility of reduced cotton yield as a result of delayed planting deserves serious consideration. The effects of late planting appear variable and differ depending on geographical area considered as well as the cultivar grown. Abbot (*1965*) reported little difference in yield of Deltapine-type cotton planted at Phoenix as late as May 15. Farr (*1976*), however, found that yield declined in Deltapine-type cottons planted in Arizona after April 25. Furthermore, at Yuma, Ariz., Deltapine-type cotton yielded highest when planted between March 15 and April 1 (Jackson and Tilt *1970*). Yields of Acala and Pima-type cottons at Phoenix were reduced when planted after April 15 (Abbot *1965*) and after mid- to late March, respectively (Kittock, unpublished data).

At the higher elevation of Safford, with its cooler spring temperatures, emergence occurs later than at lower elevations (50 percent or more moths emerge after June 1; Wene et al. *1965*, fig. 1). The authors reported that first cotton squares were usually found about June 5 in the Safford area. Thus, larvae hatching from eggs deposited on the young cotton plants have available a source of host material. Furthermore, they indicated that the earliest practical planting date in the Safford area is about April 1, and most cotton is planted around April 15. Thus, delaying planting of cotton so first squares do not appear until July 1, to escape exposure to high moth populations, appears to be impractical in that area.

Another consideration in regard to pink bollworms is delayed crop maturity as a result of delayed planting. Adkisson et al. (*1962*) pointed out that under Texas growing conditions, the availability of late-season bolls (after Sept. 15) increased the probability of higher numbers of overwintering diapausing larvae. Kittock et al. (*1975*) reported similar findings in Arizona and found that the late fall population of pink bollworm diapausing larvae was significantly correlated with the number of immature bolls remaining on the cotton plant at harvesttime. Thus, the decision to delay planting to escape initiation of pink bollworm infestations also must be carefully weighed in terms of the potential for increasing numbers of the insect late in the growing season.

LATE-SEASON PINK BOLLWORM INFESTATIONS

Cotton grown in Arizona and other areas of the Southwestern United States often remains in the ground for 10 to 12 months (Willet et al. *1973*). Pink bollworm populations develop slowly until early July. Thereafter, until late

September, insecticides may be needed to protect the current season's crop. Typically, cotton begins to fruit in early June and peaks in early to mid-July. a representative Deltapine cotton boll-set curve and calculated number of diapausing pink bollworm larvae per acre for Arizona, as taken from Kimball et al. (*1977*), are shown in figure 2. The data used to develop the curves were taken from Vail et al. (*1978*) and Kittock (unpublished data) and were obtained at Parker, Ariz.

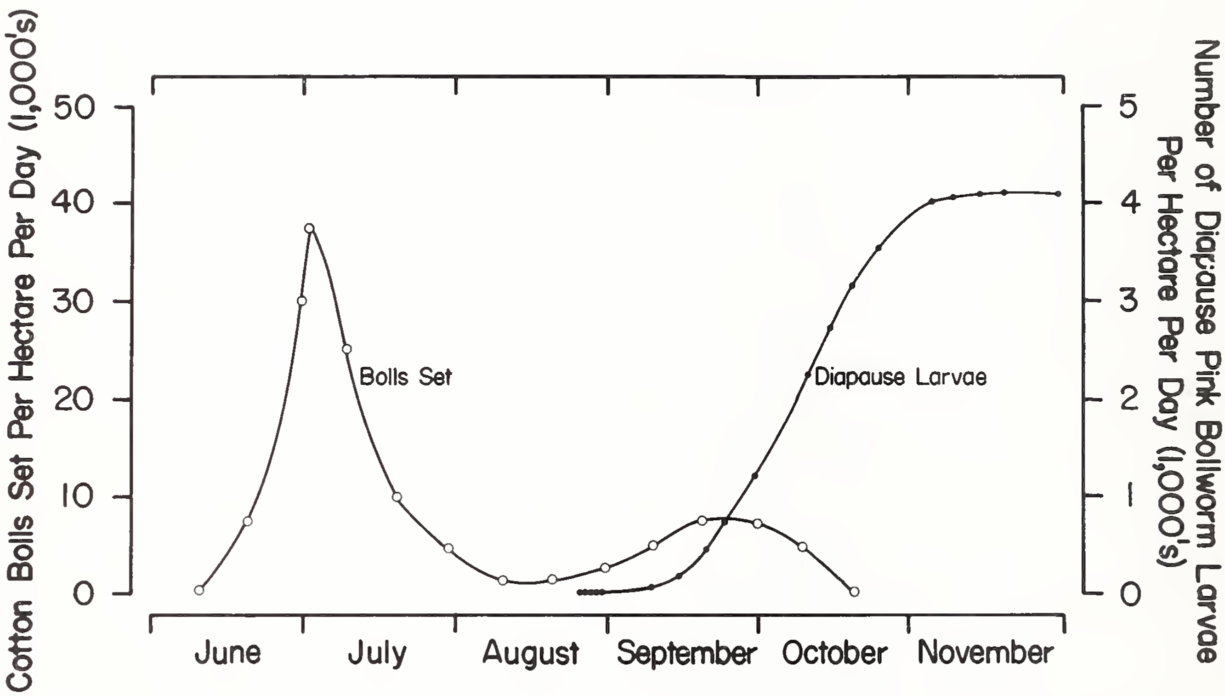

Figure 2.--Mean number of 'Deltapine 16' cotton bolls set and mean number of diapause pink bollworm larvae per hectare per day. From Kimball et al. *1977*.

Approximately 85 percent of the total cotton bolls were set by September 15. Bolls set after late August to mid-September may not mature or may produce fiber of low quality (Bennett et al. *1967*). Cotton usually fruits until frost. Thus, diapausing pink bollworm larvae develop in bolls that may not contribute to yield but do provide a source of pink bollworm infestation for cotton planted the following year. Diapausing larvae begin to appear in early September and high numbers occur by October 1 (Watson et al. *1975*). In most cases, over 99 percent of the diapausing larval generation develops in bolls after September 15 (fig. 2). The potential, therefore, exists for the development of crop management systems that will minimize yield losses while reducing overwintering pink bollworm populations by limiting the availability of host material after mid-September.

Various methods have been proposed to accomplish these objectives. Chapman and Cavitt (*1937*), at Presidio, Tex., manually stripped all fruiting forms from cotton plants on October 1, October 15, or November 1, and reduced the number of larvae in the soil by 75, 51, and 18 percent, respectively (table 3), as compared with the number found when fruiting forms were stripped from plants on November 15. The authors indicated that even though a small proportion

of the overwintering larvae were found in the soil as compared with those in bolls and trash in that area, they were extremely important because they were not destroyed by normal field cleanup practices.

Table 3.--*Effect of manually removing late-season cotton fruiting forms or early termination with defoliants or desiccants on late-season pink bollworm populations*

Reference	Method	Date treated	Larvae/hectare
Chapman and Cavitt (*1937*)	Hand stripping	Oct. 1	51,406
		Oct. 15	95,638
		Nov. 1	163,183
		Nov. 15	199,047
Adkisson (*1962*)	Desiccant[1]	Aug. 22	31,493
	Defoliant[2]	Aug. 22	27,788
	Untreated	---	238,973
	Desiccant[1]	Oct. 5	324,188
	Defoliant[2]	Oct. 5	327,893
	Untreated	---	442,748
Rice et al. (*1971*)	Defoliant	Sept. 26	343[3]
	--do--	Oct. 8	1,042
	--do--	Sept. 11	53
	--do--	Oct. 19	479
Kittock et al. (*1973*)	Defoliant[2]	Sept. 20	56,486
		Oct. 4	55,116
		Oct. 19	67,246
	Desiccant[4]	Sept. 20	18,829
		Oct. 4	45,727
		Oct. 19	78,005

[1]Arsenic acid.
[2]DEF.
[3]Effective spring moth emergence.
[4]Paraquat.

Adkisson et al. (*1958*) observed that recommended preharvest chemicals for cotton defoliation in Texas delayed buildup of pink bollworm infestations by reducing the food supply for development of late-season generations. They suggested that this practice could reduce the number of overwintering insects. Adkisson (*1962*) subsequently applied a defoliant or desiccant to cotton when an estimated 4 or 90 percent of the pink bollworm population was going into diapause. An important point demonstrated was that time of treatment was critical. Plots treated August 22 (4 percent diapausing larvae) had 90 percent fewer larvae per hectare than the number in untreated plots (table 3), but populations in plots treated on October 5 (90 percent diapausing larvae) were reduced only 26 percent. Similar results were obtained with early cotton defoliation in California (Rice et al. *1971*) and Arizona (Kittock et al. *1978*). The disadvantage of the treatments is that early defoliation and/or desiccation remove cotton leaves and, in fact, terminate further production, often resulting in reduced

cotton yields (Walhood *1960*, Kittock et al. *1973*) and quality (Kittock et al. *1978*).

Early cotton crop termination by water management techniques to shorten the growing season and prevent development of large overwintering pink bollworm populations is another approach that has high potential for success in certain cotton-growing areas. Willet et al. (*1973*) considered the economics of short- and full-season cotton production in Arizona. Because of the many variables involved, they could not identify a definite yield increase in top crop production (full season) over that in short-season production. The study did indicate, however, that a substantial yield loss could be sustained that would still permit increased profits resulting from reduced insecticide, water, and other management costs.

Arizona cotton growers use many different irrigation regimes. Most growers allow cotton plants to reach moderate stress before irrigating. This is consistent with the recommendations of Harris et al. (*1947* and *1959*) and Erie et al. (*1966*). Pima cotton generally needs more water stress than Upland cotton (Kittock, unpublished data).

Harris et al. (*1947*) stated that "heavy irrigation after Aug. 1 is at best a waste of water and labor, and during certain seasons may be detrimental to yield." Erie et al. (*1972*), however, reported significant yield reduction of more than 25 percent with irrigation cutoff in late July at Phoenix. Farr and Kittock (*1979*) report an average 114 kg more lint per hectare for Maricopa County, Ariz., when last irrigation was applied in mid-August than when applied in early August, and an additional 44.9 kg of lint when last irrigation was applied in early September. In the same report, a final irrigation in early September gave an average of 139 kg more lint for Pima cotton than a final irrigation in mid-August.

Watson et al. (*1978*) studied for 3 years the effects of short-season cotton on pink bollworm control in the Yuma Valley. A mid-July (July 15) irrigation cutoff significantly reduced yield, but plants receiving the last irrigation on July 29 slightly outyielded plants receiving the last irrigation on all other dates (Aug. 16, Sept. 3). Greater numbers of pink bollworm moths emerged the following spring with each subsequent irrigation cutoff date. The authors concluded that a last irrigation date of about August 1 in the Yuma Valley would both maintain crop yield and minimize the number of overwintering pink bollworm larvae.

Another method to terminate cotton fruiting, although not approved for general use at this time, is by applying plant growth regulators. Mauney et al. (*1972*) discussed the theory of selective termination of cotton fruiting forms during early September with plant growth regulators. They concluded that such a treatment could reduce numbers of diapausing pink bollworm larvae in relation to the reduction of immature bolls available and have the least adverse effect on cotton yield and quality because leaves remain on the plant and existing green bolls continue to develop normally.

Kittock et al. (*1973*) showed from 1971 tests that certain plant growth regulators used alone selectively reduced the number of immature late-season green bolls and the number of diapausing pink bollworm larvae but reduced yields and/

or quality of cotton produced. Subsequent studies, 1972-77, revealed that combinations of rapidly acting and persistent plant growth regulators were more effective than any one material applied alone for selectively removing late-season, immature green bolls (Bariola et al. *1976*, Kittock et al. *1978*, Vail et al. *1978*). Rapidly acting plant growth regulators removed existing fruiting bodies, and persistent plant growth regulators in the mixtures prevented recovery and regrowth of plants. Treatments were developed that effectively removed late-season cotton fruiting forms and reduced pink bollworm fall populations over 90 percent without significantly affecting cotton yields (Bariola et al. *1976*) or seed and fiber quality characteristics (Kittock et al. *1978*).

Timing of the application was critical to achieve maximum effect on pink bollworm reduction and minimum effect on yield. Proper timing is related to number of days from flowering to boll maturity and the anticipated harvest date. Flowering to boll maturity can vary from about 45 days for July flowers to 75 to 90 days for early September flowers, and treatment must be applied to abort only those fruiting forms which have little probability of contributing to yield.

A brief summary is shown in table 4 of the most acceptable treatments developed. Some of the considerations regarding implementation of these treatments into cotton crop management systems are discussed below.

Five plant growth regulators have been effective in various mixtures. Two slow-acting, but persistent, materials are chlormequat--[(2-chloroethyl) trimethylammonium chloride], and chlorflurenol--[methyl 2-chloro-9-hydroxyfluorene-9-carboxylate]. They are each effective when used at 0.56 kg ai/ha in mixtures with a fast-acting plant growth regulator. Neither material is acceptable when used alone. Both are registered for noncrop use, but neither is presently registered on food or feed crops. Chlorflurenol residue was found in cottonseed up to 0.12 ppm, but no residue was found in refined oil (Kittock et al. *1978*). Since cottonseed is an important supplement for cattle feed, residues will be an important consideration by regulatory agencies concerned with registration for use of the materials for cotton crop termination.

Three fast-acting, but nonpersistent, chemicals appear adequate for chemical termination when used in combination with one of the slow-acting, persistent types mentioned. These are: (1) 2,4-D, (2) dicamba [(3,6-dichloro-*o*-anisic acid)], (3) Pennwalt TD-1123 [(3,4-dichloroisothiazole 5-carboxylic acid)]. All but TD-1123 are registered for use on food crops. The most effective, 2,4-D, is cheapest and effective at the lowest rate, 0.028 kg ai/ha, in mixtures. No residue of 2,4-D was found in seed from treated plants (Kittock et al. *1978*); however, germination and emergence of seed in immature bolls is severely reduced by 2,4-D (Kittock, unpublished data). The extent of effect on seed depends on the proportion of the bolls that are immature at the time of treatment (Arle and Kittock *1973*). Also, affected leaves, squares, and flowers do not abcise, resulting in excess trash in mechanically picked cottonseed. The germination and seedling emergence problems from 2,4-D treatment can be largely eliminated by reducing the concentration to 0.019 kg ai/ha and increasing the application rate of the persistent plant growth regulator (Kittock et al. *1978*); however, application of 2,4-D at rates as low as 0.008 kg ai/ha has not reduced the trash problem.

Dicamba (0.056 kg ai/ha) is also effective for chemical termination, though not as efficient as 2,4-D, but allows leaf abcission; however, it may affect seedling emergence slightly.

Table 4.--*The effect of mixtures of plant growth regulators on cotton lint yield, immature bolls at harvest, and late-season pink bollworm populations expressed as percentages of untreated checks*

Reference and treatment	Year of test	Percent reduction in: Yield (Percent of check)	Immature bolls	Pink bollworms
Bariola et al. *1976*:				
2,4-D + chlormequat	1972	--	99.6	93.5
2,4-D + chlorflurenol	1973	-5.1	94.1	92.7
2,4-D + chlorflurenol	1974	-0.4	98.0	99.6
Kittock et al. *1978*:				
2,4-D + chlorflurenol	1972	4.1	98.9	90.0
2,4-D + chlorflurenol	1972	--	98.9	41.0
2,4-D + chlorflurenol	1973	8.9	83.1	36.0
2,4-D + chlormequat	1974	12.4	98.6	100.0
Pennwalt TD-1123 + chlorflurenol	1975	10.1	100.0	82.9
Pennwalt TD-1123 + chlorflurenol	1976	-1.8	92.2	97.1
Pennwalt TD-1123 + chlorflurenol	1976	-3.0	85.9	96.4
MCPD + chlormequat	1976	12.7	80.4	97.9
Dicamba + chlormequat	1976	13.8	87.0	97.9
Mean		3.8	79.7	85.4

TD-1123 treatment has no effect on seedling emergence if treatment is properly timed and also allows leaves and other plant parts to abcise. In fact, TD-1123 enhances subsequent cotton defoliation (Cathey *1978*, Kittock et al. *1978*). TD-1123 at 1.21 kg ai/ha is not as effective for chemical termination as 2,4-D. It is about as effective as dicamba on Upland cotton, but does not work well on Pima cotton. Thus, the most promising treatments appear to be TD-1123 at 1.21 kg ai/ha plus chlorflurenol or chlormequat at 0.56 kg ai/ha for Upland cotton. Large-scale tests, which are needed to ultimately prove or disprove the effectiveness of chemical termination for control of pink bollworm, must await registration of a suitable treatment.

SUMMARY

Planting cotton later than normal in Arizona and California provides minimum numbers of early season fruiting forms (squares) as host material for initi-

ation of spring pink bollworm infestations; however, 30-day differences in cotton planting dates resulted in maximum differences of 15 days to significant flowering. Furthermore, the latest acceptable planting date without yield reduction results in the production of squares when significant numbers of moths have emerged from overwintered larvae. Delayed maturation of the cotton crop as a result of delayed planting also must be carefully considered since the potential of higher late-fall pink bollworm populations is increased (Adkisson et al. *1962*, Kittock et al. *1975*).

Defoliation or desiccation to terminate cotton growth reduces overwintering pink bollworm populations but also, if not timed properly, can significantly reduce cotton yields and quality.

Early cotton crop termination, by applying the last irrigation on about August 1, is effective in Yuma Valley for reducing overwintering pink bollworm populations without reducing yields. It has been effective in other areas as well, but the termination date must be adjusted for local factors such as soil type. Early planting and early crop termination appear to be essential under southern California and Arizona cotton growing conditions because: (1) early planting favors a heavy early boll set before the extreme summer heat and, therefore, generally results in higher total yields (particularly in Pima cotton); (2) late cotton usually has poorer fiber quality; (3) losses from insect damage, boll rot, and storm damage are more common in late-planted cotton; and (4) an early frost can seriously reduce lint yield of late-planted cotton.

Selectively removing immature late-season bolls that serve as host material for the development of diapause pink bollworms is an effective method of reducing overwintering populations. Several chemicals accomplish this objective without reducing cotton yield or quality. Combinations of a rapidly acting plant growth regulator with a persistent material appear to be necessary and effective, although more efficient plant growth regulators may become available that will work adequately when applied alone; however, none of the materials are presently registered for use on cotton.

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METHODS FOR REDUCING WINTER SURVIVAL OF THE PINK BOLLWORM

By T. F. Watson[1]

INTRODUCTION

The pink bollworm, *Pectinophora gossypiella* (Saunders), extended its geographical boundary in late 1965 to include the entire southwestern cotton-growing area of the United States (Noble *1969*).[2] Since that time, most of the cotton grown in Arizona and southern California has required insecticidal treatments sometime during the growing season to prevent economic losses from damage caused by this pest. Although effective chemical control can be achieved, it is the least desirable method of coping with this problem, primarily because of the induced secondary outbreaks of pests such as the cotton leafperforator, *Bucculatrix thurberiella* Busck (Watson and Johnson *1972*) and the tobacco budworm, *Heliothis virescens* (F.) (T. F. Watson, unpublished data).

The potential for a more satisfactory solution to the pink bollworm problem lies in cultural control, a method aimed at reducing overwinter survival of diapausing larvae. Because this pest passes the winter in the soil or crop residue in the field in which it developed, it is especially vulnerable to destruction by mechanical and cultural means.

Although several cultural or mechanical practices have been shown individually to reduce overwintering populations of the pink bollworm, it takes a combination of such practices to effectively control this insect during the overwintering stage. Adkisson and Gaines (*1960*) have listed the combination of practices that provided effective control in Texas as follows: (1) defoliate or desiccate the mature crop to cause all bolls to open at nearly the same time, expediting machine harvesting; (2) harvest the crop as early and in as short a time as possible; (3) shred stalks immediately following harvest; (4) plow stalks under immediately, preventing regrowth of new fruiting forms that might provide food for diapausing larvae; (5) prepare land for planting of the subsequent crop, including preplant irrigation in arid areas; and (6) plant new crops during a designated planting period that allows for maximum "suicidal emergence" of moths from overwintering larvae. The combination of practices developed in Texas provided the growers with a control program for the pink bollworm so successful that insecticides are seldom needed (Adkisson *1972*).

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[2] The year in italic, when it follows the author's name, refers to Literature Cited, p. 33.

Since 1966, extensive research has been conducted in Arizona and southern California on methods to culturally control the pink bollworm in these locations, characterized by dry, mild winters, resulting in longer growing seasons and greater overwinter survival than found in most other pink bollworm-infested areas of the United States. The primary objective in the studies has been to develop means of reducing overwintering populations to levels sufficiently low to prevent development of economic infestations during the subsequent growing seasons.

EFFECTS OF INDIVIDUAL PRACTICES

Stalk Shredding

In the rainbelt area of Texas, most overwintering larvae are found in the seed of the bolls in which they develop (Chapman et al. *1960*). In the arid Southwest, however, a large percentage of the diapausing larvae leave the bolls to overwinter in free cocoons on or in the soil, usually attached to debris or soil particle (Watson et al. *1970*, Rice and Reynolds *1971*). Since research conducted in Texas showed that moth emergence could be reduced significantly by the use of stalk shredders (Chapman et al. *1961*), similar research was conducted in Arizona to attempt destruction of that segment of the overwintering population that remained in the bolls. Because of the long growing season and cessation of insecticidal treatments late in the season, large diapause populations developed in the late-season boll load, which, if destroyed, would significantly reduce the number of overwintering larvae.

Results of these tests showed that none of the commercially available shredders tested, or modifications thereof, was effective in reducing the overwintering larval population remaining in the bolls (Watson et al. *1970*). The shredding machines used in these tests are described in table 1.

The effects of various shredding treatments conducted at Phoenix, Ariz., in 1966-67, are shown in figure 1. Spring moth emergence from all shredding treatments equalled or exceeded that of the nonshredded check.

The following fall and winter, 1967-68, further shredding tests were conducted at Mesa and Safford, Ariz. Essentially the same results were obtained as in the previous tests, that is, shredding caused no reduction in spring moth emergence. These data are shown in figure 2.

Even though stalk shredding proved to be ineffective as a direct control measure against overwintering pink bollworm larvae, indirectly it was beneficial and is an essential, contributory component to good cultural control. This practice permits the more uniform and deeper burial of the shredded plant debris during subsequent plowing operations, which enhances the effects of other cultural operations, such as plowing and winter irrigation treatments.

Soil Tillage Practices

In the disposal of crop residue and the preparation of soil for planting subsequent crops, various soil tillage operations are routinely performed, usually during the winter or early spring. These operations were evaluated in a

number of tests at various locations in Arizona, for effectiveness in reducing spring and moth emergence.

Table 1.--*Description of machines used in stalk shredding treatments*

Year, location and treatment	Shredder description	Width of cut	Shaft speed	Tip speed	Ground speed
		Number of rows	*Revolutions per minute*	*Feet per minute*	*Miles per hour*
1966-67, Phoenix					
1.	None[1]	---	---	---	---
2.	Rotary - 2 blades, 2 shear plates, backplate and guides	2	743	11,665	4.4
3.	Rotary - single blade, no shear plates, backplate or guides	2	743	11,665	4.5
4.	Vertical flail - 2 forward rotating, hinged knife	2	2,000	6,160	3.4
5.	Parallel inclined shafts, serrated sickle sections	1	1,800	3,740	4.5
1967-68, Mesa					
1.	None[1]	---	---	---	---
2.	Rotary - 2 blades, 2 shear plates, backplate and guides	2	743	11,665	2.5
3.	Vertical flail - backward rotating hinged knife	2	1,460	9,200	2.5
4.	Vertical flail - backward rotating hinged knife	4	1,010	5,700	2.5
1967-68, Safford					
1.	None[1]	---	---	--	---
2.	Vertical flail - backward rotating hinged knife	2	1,620	11,000	2.2

[1]Nonshredded check.

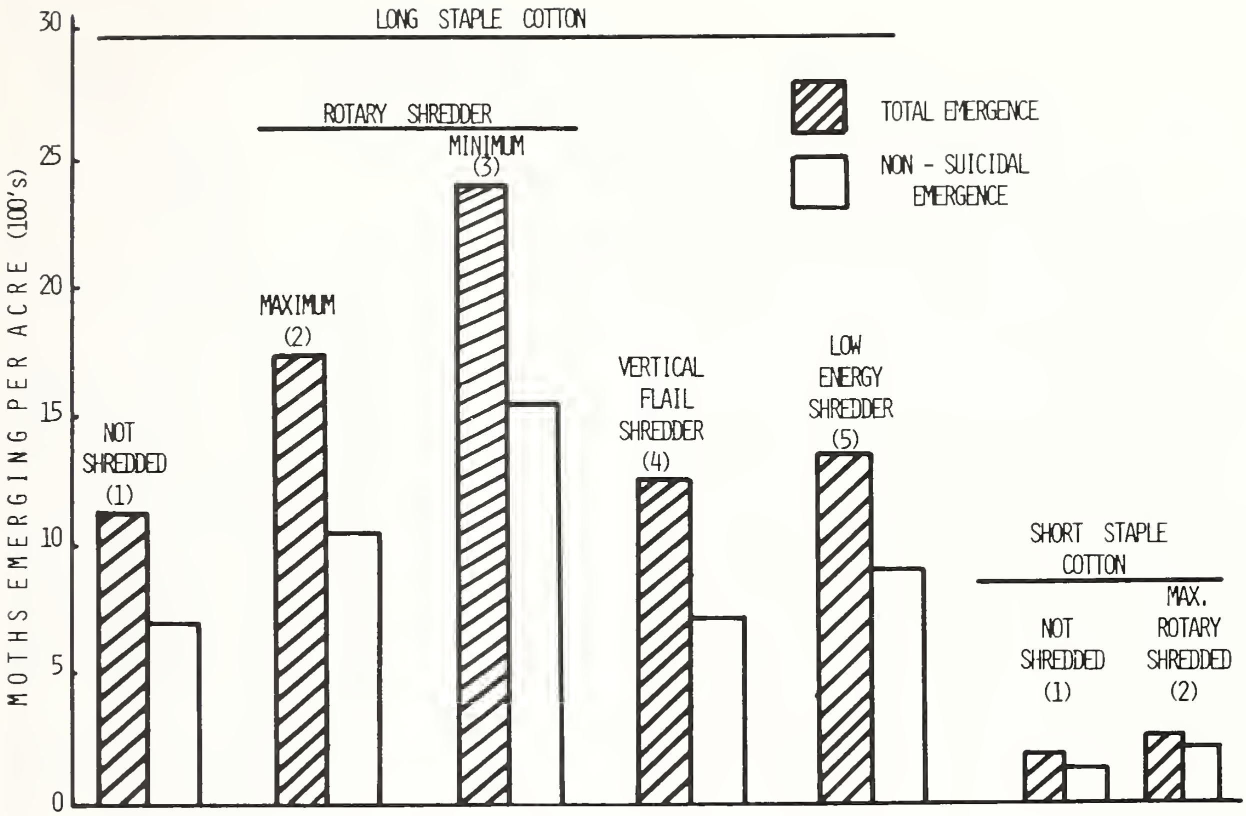

Figure 1.--Emergence of pink bollworm moths from cotton plant residue subjected to various treatments at Phoenix, Ariz., in 1966-67.

At Phoenix, Watson and Larsen (*1968*) compared eight soil-tillage practices for effectiveness in reducing spring moth emergence. These practices and moth emergence data are presented in figure 3. The greatest moth emergence occurred where only a disking operation was performed; the least occurred where the soil was finely pulverized with a rototiller (fig. 3). Rototilling the soil, however, is not a normal farm practice and, in addition to adversely affecting the physical characteristics of the soil, requires a large amount of energy relative to other operations.

The most practical and effective tillage operation, following stalk shredding, was deep, moldboard plowing subsequent to a disking operation (table 2). In a deep plowing operation, the soil is turned to a depth of about 6 inches. This provided the most uniform complete burial of surface trash and soil. This is extremely important since Rice and Reynolds (*1971*) reported that 81 percent of the overwintering population of pink bollworms is located in the top 2 inches of soil. In experiments where deeper plowing was employed, the turnover of surface material was less thorough, and, consequently, plant debris and surface-area soil were stratified throughout the 12-inch plow depth.

The time tillage operations are performed is also important. The earlier in the fall or winter that the soil is plowed, the greater is the decomposition of plant material and overwinter larval mortality.

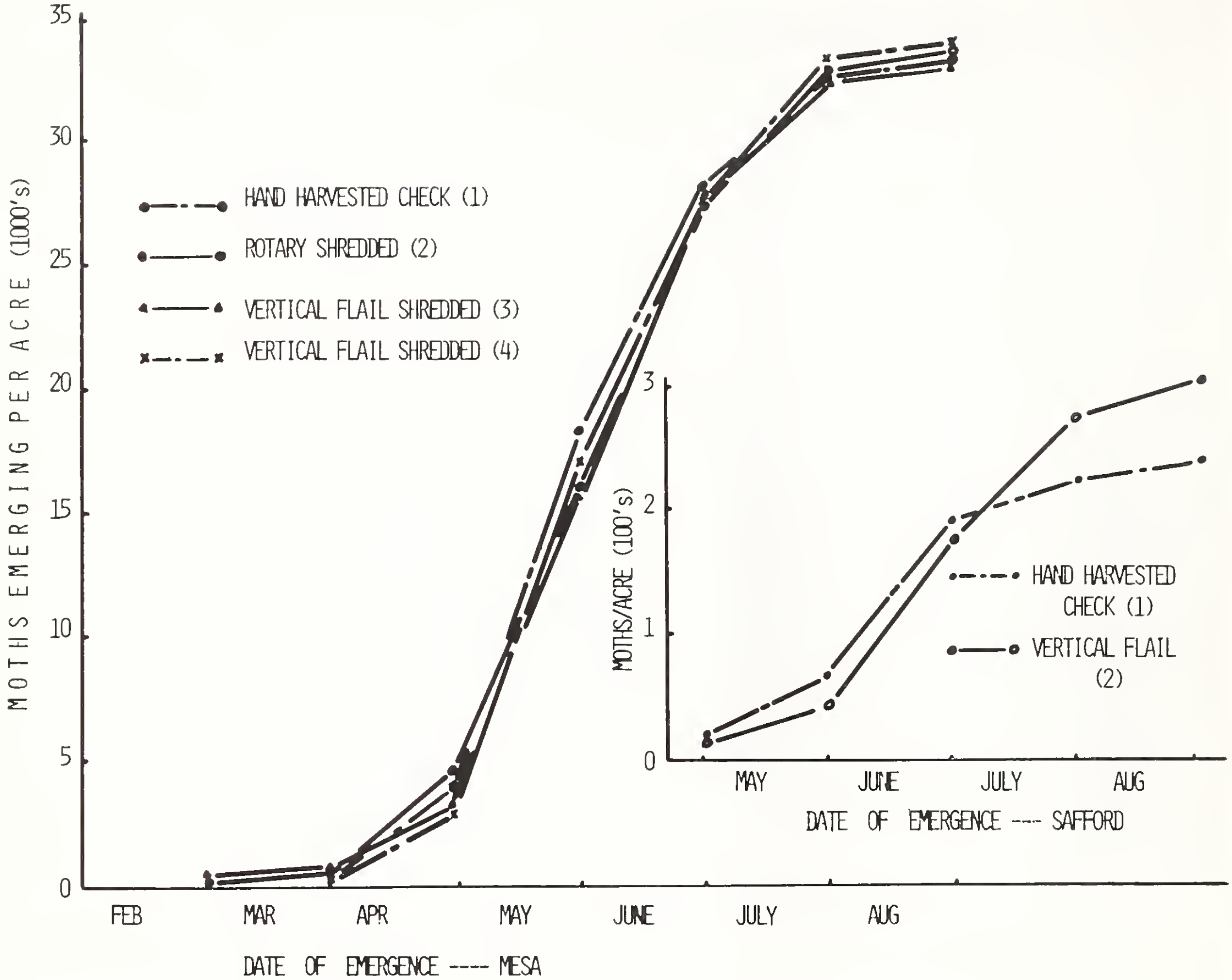

Figure 2.--Cumulative emergence of pink bollworm moths from cotton plant residue subjected to various shredding treatments at Safford and Mesa, Ariz., in 1967-68.

Research has also shown that with each subsequent spring tillage operation in preparation for planting, pink bollworm moth emergence is reduced. For example, spring disking followed by listing results in successive reductions in moth emergence as compared to that where no spring operation is performed (T. F. Watson, unpublished data).

Irrigation

Moisture is important to overwintering pink bollworm larvae in a number of ways. Slosser and Watson (*1972*) found that extremely dry or wet soil conditions adversely affected overwinter survival. Conditions for optimal survival were those in the 10 to 15 percent soil moisture range. Extremely dry conditions normally do not occur for long periods during the winter months so the most reliable means of adversely affecting overwinter survival is by irrigating.

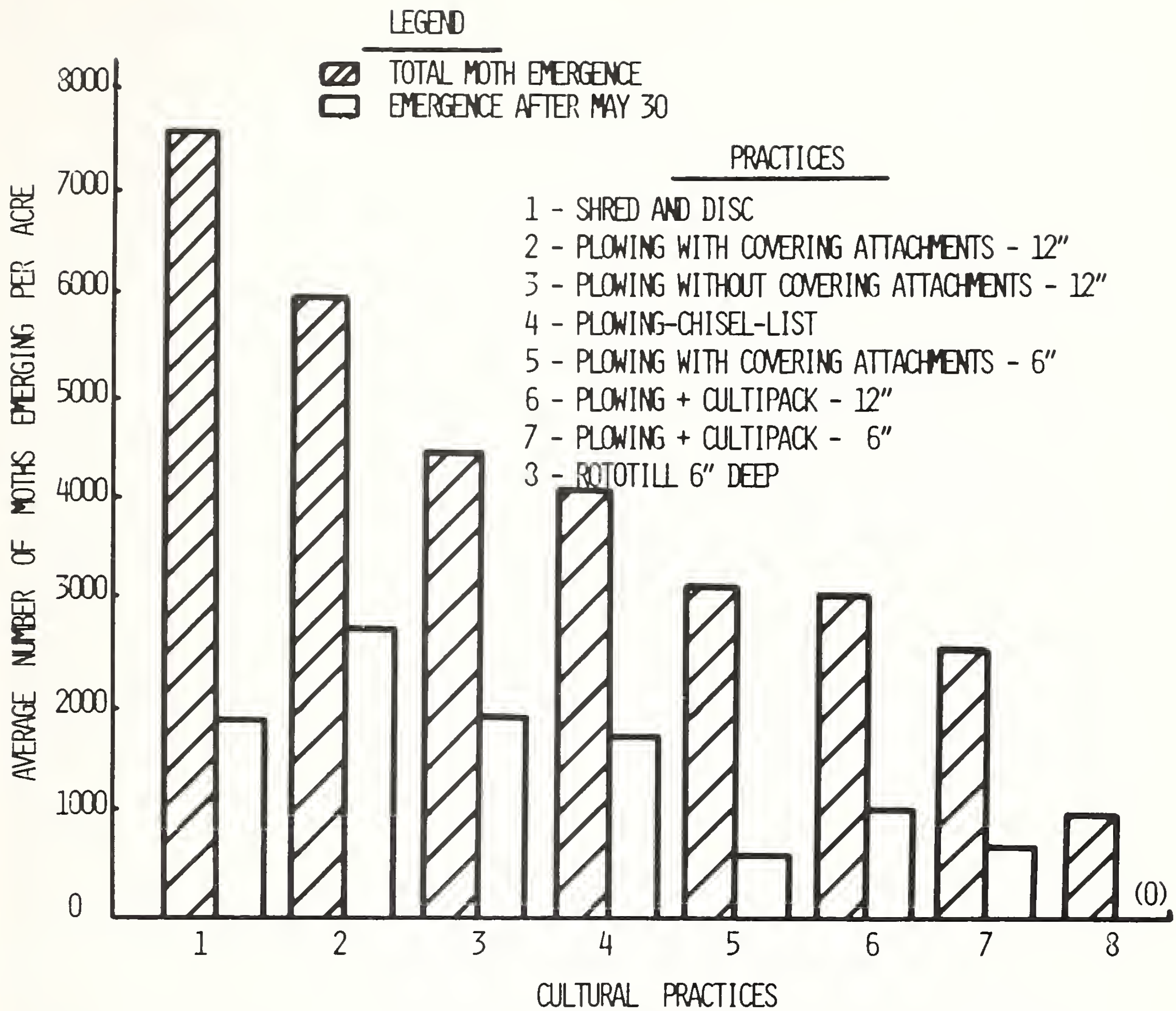

Figure 3.--Influence of eight methods of burying plant debris on pink bollworm moth emergence, both total and effective. Phoenix, Ariz., 1967.

Other related factors--such as type of tillage practices before and after irrigations--are important, and effects are supplementary to those of the irrigations. In general, each irrigation during the winter or early spring months, reduces moth emergence. Tables 3 and 4 present the results of irrigation experiments conducted in Arizona. Table 3 shows that any type of irrigation practice greatly reduces moth emergence as compared with comparable tillage treatments without irrigation. Table 4 shows similar reductions in moth emergence with irrigations on plowed or rototilled plots, but no reduction where the plots were only disked. This probably relates to the fact that in disked plots the diapausing larvae are left near the soil surface, lessening exposure of larvae to sustained high moisture levels and permitting moth escape. These tables also illustrate the effectiveness of subsequent tillage operations in reducing moth emergence and the additional reductions caused by irrigations following the tillage practice.

Table 2.--*Effect of various cultural practices on pink bollworm moth emergence, Mesa, Ariz.*

Cultural practice	Mean No. moths emerging per acre[1]			
	1967-68		1968-69	
	Effective[2]	Total	Effective[2]	Total
Remove debris, disk	520	5,760	100	533
Shred, disk, rototill twice	360	6,520	---	---
Remove debris only	880	7,280	267	1,033
Shred, disk, rototill	880	8,520	367	1,467
Shred, disk, plow	520	8,920	400	1,567
Shred, disk	1,680	12,400	---	---
Shred only	2,240	14,880	1,467	2,900

[1] Moth emergence represents means for each treatment from 5 and 6 plowdown dates, respectively, for 1967-68 and 1968-69.
[2] Moths capable of initiating an infestation.
Note: Dashes indicate no data.

Table 3.--*Influence of various winter and spring irrigation and tillage treatments on moth emergence, Mesa, Ariz.*

Irrigation and tillage treatments[1]	Mean No. moths emerging per acre[2]	Statistical significance (0.25)
None	3,400	a
Border irrigated;		
Jan. 2	1,600	ab
Jan. 2 and 15	1,200	b
Jan. 2 and 15 and Feb. 15	800	b
Mar. 15	600	b
Feb. 15 and Mar. 15	600	b
Furrowed-out Mar. 15:		
No irrigation	2,400	ab
Irrigated Mar. 15	600	b

[1] All plots were uniformly shredded, disked, and plowed on Jan. 2, 1969.
[2] Means of 5 replications.

Table 4.--*Influence of spring irrigation and tillage on moth emergence in 1968*

Irrigation and tillage treatments[1]	Pink bollworm moth emergence			
	Mesa		Yuma	
	Plowed	Rototilled	Plowed	Disked
Nonirrigated	118	86	87	102
Early spring irrigated	20	37	29	137
Furrowed out:				
Nonirrigated	17	19	---	---
Irrigated	7	9	---	---

[1] An initial uniform treatment common to all plots consisted of shredding, disking, and plowing on Dec. 28 at Yuma and Jan. 5 at Mesa.

Note: Dashes indicate no data.

Fye (*1973*) studied the effects of simulated rainfall and irrigations on moth emergence. He concluded from these studies that rainfall seals the soil surface and prevents a majority of the moths from escaping; however, his simulated irrigation studies revealed little difference in moth emergence between irrigated and nonirrigated treatments.

Research has also shown the beneficial effects of irrigations on larval survival following unusually dry winters (T. F. Watson, unpublished data). Under these conditions, late winter or early spring irrigation have resulted in greater moth emergence. This substantiates the conclusions reported by Slosser and Watson (*1972*) that conditions either too dry or too wet are detrimental to survival. Watson et al. (*1973*) have also reported on the necessity of adequate moisture to stimulate pupation of diapausing larvae.

Crop Rotations

Another practice that may aid in reducing overwinter survival is crop rotation. Moth emergence has been shown to be reduced when a winter grain crop follows cotton (T. F. Watson, unpublished data). Mueller et al. (*1974*), however, have shown that effective spring moth emergence may be as great or greater from a fall-planted crop, such as alfalfa or barley, than from a subsequent planting of cotton. The effect of a cover crop and irrigations on delaying spring moth emergence is that they result in a greater percentage of the moths emerging nonsuicidally, that is, after cotton has commenced squaring. Presumably, the lower temperatures occurring in the shielded and wet fields delay pupation and subsequent moth emergence. This is consistent with the data presented by Watson et al. (*1973*) on the effects of temperature and moisture on diapause termination.

INTEGRATION OF CULTURAL PRACTICES

Previous research has demonstrated that a number of cultural practices will individually reduce overwinter survival of the pink bollworm. These studies have further shown that in combination, with each additional practice imposed on cotton, for example, disking following shredding, plowing following disking, and irrigation following plowing, there is an additional reduction in spring moth emergence. With the long growing season and mild winters in Arizona, however, overwinter survival and spring moth emergence are still too great to prevent economic infestations during the next growing season.

To supplement the effects of the combined winter cultural practices in reducing overwinter survival, research was conducted to determine the effects of shortening the growing season by earlier plowdown dates than those normally employed. These plowdown dates ranged from September 3 to January 5 in both years of the study, most of which were too early to accommodate the routine operations of the grower. The results did demonstrate, however, that with each delay in plowdown, greater moth emergence occurred the following spring, significantly greater for plowdown dates in December and January (table 5) (Watson et al. *1974*).

Even though the earlier plowdown dates were impractical, the study did show the effects of the later plowdowns in perpetuating large, late-season populations, most of the individuals of which were entering diapause. This prompted a subsequent study aimed at accomplishing essentially the same results as early plowdown by late-season management of irrigation water. Results of this study are reported in the section on crop management.

Table 5.--*Effect of plowdown dates on number of pink bollworm moths emerging the following spring, Mesa, Ariz.*

Plowdown date		Mean No. moths emerging per acre			
		1967-68		1968-69	
1967-68	1968-69	Effective	Total	Effective	Total
---	9/3	---	---	40	160
---	9/17	---	---	320	600
10/2-6	10/1	257	3,971	400	760
10/17-18	---	514	7,371	---	---
10/31-11/1	11/1	914	6,647	360	1,520
12/5	12/3	1,800	10,800	960	2,480
1/5	1/3	1,571	17,114	1,040	3,480

Note: Dashes indicate no data.

SUMMARY

The use of scheduled applications of insecticides to control the pink bollworm is an unsatisfactory method of coping with this problem. Effective pink bollworm control can be achieved, but the development of secondary pest problems, such as the cotton leafperforator and tobacco budworm, makes the approach both environmentally and economically undesirable.

Cultural control has been demonstrated to be the most satisfactory solution to the pink bollworm problem in Texas. It can also be a satisfactory and necessary solution to the problem in other areas of the southwestern United States. To be effective, however, it will require shortening the growing season for cotton to prevent the development of large diapausing populations, coupled with a combination of fall and winter cultural practices--including shredding the stalks, disking, plowing, and winter irrigation or winter cropping--to destroy overwintering larvae or prevent moth emergence.

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INSECTICIDES FOR CONTROL OF PINK BOLLWORM POPULATIONS

By H. T. Reynolds[1]

INTRODUCTION

Since the invasion of the hot arid Colorado desert areas of Arizona and southern California by the pink bollworm in the early and mid-1960's, cotton farmers have relied primarily upon insecticides for control of this pest. The environment of this area provides nearly ideal conditions for maximum reproduction and survival. Also, the prevailing long production season results in a large number of generations per season (Slosser and Watson *1972*).[2] This leads to immense numbers of larvae entering the winter period in diapause (Kittock et al. *1975*). Although winter mortality of diapausing larvae is great, sufficient numbers survive to require insecticide treatments early in the fruiting period the succeeding production season. Treatments for pink bollworm often start in mid-July or shortly after and are scheduled weekly until about the first frost or defoliation.

Prior to invasion, cotton production required relatively little insecticide; now, as many as 10 to 15 applications are made in some areas. Increasing insecticide prices have made this a costly procedure; furthermore, effects on the environment are believed to be significant. Certainly, nontarget populations are seriously affected, depletion of beneficial insect populations being particularly serious.

The heavy reliance upon insecticides has kept cotton production viable financially, despite high costs and some yield reductions. In contrast, most cotton production areas of the world, which are ecologically well suited to pink bollworm development, depend upon cultural controls as the first and main line of defense against losses to this pest; insecticides are used, but only as a last resort or as a supplement to the cultural controls. In such areas, comparatively few insecticide applications are needed--usually two to three at most when pink bollworm control alone is needed.

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[2] The year in italic, when it follows the author's name, refers to Literature Cited, p. 39.

MANAGEMENT WITH INSECTICIDES

In attempting to develop insect pest management programs in which insecticides are incorporated, all available methods are used to attain the most efficient use of the chemicals while minimizing their disruptive effect on beneficial insect populations. It is imperative that the pink bollworm populations be monitored carefully (see section on "Pink Bollworm Monitoring Methods") in order that insecticides may be applied precisely when needed. Timing applications is particularly critical in the case of the pink bollworm, as effectiveness is largely predicated upon kill of the adults or moths. Comparatively few larvae are killed by insecticides since it is impossible to kill the larvae after they enter the boll.

The moths lay eggs in sites somewhat inaccessible to insecticide deposits, and when bolls are present the tiny larvae enter the boll on which the eggs are laid (Tsao and Lowry *1963*). These larvae may move around the exterior of the bolls to some extent, but enter shortly after hatching. As a consequence of this behavior, insecticide treatments are not as effective as when applied against insects with larvae exposed for longer periods. As a result, infestation is limited primarily by killing the adults. When field monitoring shows insecticide treatment is necessary, it generally takes about 2 weeks for the boll infestation to drop to low numbers (H. T. Reynolds, unpublished data).

Once it is necessary to start insecticide applications, most farmers and pest control advisors have maintained treatments on a schedule basis, approximately once a week, throughout the remaining production season. Escalating insecticide costs have made this procedure very expensive. Careful monitoring of the cottonfields, in which application need is determined by both the pink bollworm population and by the stage of plant growth (for example, availability of susceptible bolls), often shows that application can be delayed or omitted. While this is seldom done in practice, it is gaining more acceptance by growers, especially in eastern and central Arizona.

Specific recommendations, such as the choice of insecticides to control pink bollworm and the suggested dosage per acre, vary according to area and are continually being updated. Accordingly, specific instructions for use are omitted here. Data indicate monocrotophos[3] and carbaryl[4] are effective insecticides (Hopkins et al. *1979*). Although these compounds remain effective, the recent availability of the synthetic pyrethroids, which can be used where it might be hazardous to use the former materials, has reduced their use to a much smaller percentage of the market. The switch to the pyrethroids, although more expensive, has taken place because they are highly effective on pink bollworm and very effective also on difficult-to-kill species such as the *Heliothis* complex and the cotton leafperforator (U.S. Department of Agriculture *1979*).

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[3] Dimethyl phosphate ester with (*E*)-3-hydroxy-*N*-methylcrotonamide.
[4] 1-naphyl methylcarbamate.

INSECTICIDE RESISTANCE

The inexorable development of insecticide resistance is one of the most difficult problems facing the cotton industry. Virtually all of the important insect and spider mite species that are major pests of cotton in the Western States have already developed resistance to one or more pesticide chemicals available to the cotton farmer. In the case of a few species, the tobacco budworm and cotton leafperforator, for example, the choice of effective insecticides remaining to the farmer is extremely limited, and the loss of even one more to resistance could place effective control in jeopardy.

The pink bollworm developed resistance to DDT[5] in several areas of Mexico, particularly in Torreon in the late 1950's after about 11 or 12 years of selection pressure. Tests made in the laboratory in about 1962 demonstrated resistance had developed also in Texas near Presidio and Pecos (Lowry and Berger *1965*). DDT is no longer used on U.S. cotton, of course, nor are any of the other related organochlorine insecticides. At this time, no substantiated reports of resistance are available concerning any other types of insecticides, for example, organophosphorous and pyrethroid, although some believe that certain organophosphorous and carbamate compounds may be slightly less effective than when first used. No laboratory data substantiate resistance development, however, and reports of failures in field practice believed due to resistance have not been received. Nevertheless, the fact that DDT resistance developed in some areas years ago is worrisome. There are several reasons for concern. One, of course, results from experience accumulated over the years which indicates that once resistance has been established in a population it develops more rapidly to other types of insecticides. It is not known, however, whether the pink bollworm in Arizona and California originated from a DDT-resistant or susceptible population.

The multiple applications of insecticides prevailing, generally at high dosage rates per acre and often incorporating a second insecticide mainly for pink bollworm (now for tobacco budworm also), have resulted in extremely harsh pressures for the selection of resistant populations. This selection process involves nontarget as well as target species. One example involved the cotton leafperforator. Occasional applications of trichlorfon[6] and other organophosphorous insecticides had been used successfully for more than 10 years prior to invasion of the Imperial Valley by the pink bollworm in 1965. Approximately 1 1/2 years of extremely severe selection pressure by organophosphorous insecticides applied for pink bollworm control resulted in total ineffectiveness of all known insecticides of this general structure on cotton leafperforator (H. T. Reynolds, unpublished data). Thus, a different type of insecticide had to be incorporated with the pink bollworm sprays whenever the perforator populations threatened economic damage. This practice, which at that time was necessary, placed an even higher pressure for selection of resistant populations of other species in the cottonfields, and concomitantly pre-existing levels of resistance became even higher.

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[5] 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane.
[6] Dimethyl(2,2,2-trichloro-1-hydroxyethyl)phosphate.

Certains crops can no longer be grown in a few areas of the world because available insecticides are no longer effective. The consequences of such a disaster to cotton production in Arizona and California are foreboding. Generally, the chemical industry has discovered and developed new insecticides at a pace to keep ahead of the ever-intensifying resistance problem, but the enormous development cost, increasingly stringent demands for registration, short period of patent protection after registration for commercial use, and other factors, all conspire to make it more difficult to keep up with the demand. As a consequence, there is a desperate need to prolong the life of useful insecticides already available. The only major, feasible route known to prolong the life of these chemicals is to reduce selection pressure. Prevailing practices in insecticide use are antithetical to this goal.

EFFECTS OF PINK BOLLWORM SPRAYS ON SECONDARY PESTS

Most agricultural fields have three general categories of insect pests:

1. *Key (primary) insect pests*.--These are species that infest the crop each year. Generally, beneficial insects and environmental conditions are not enough to keep a key pest below population levels that cause economic damage. Insofar as practical, noninsecticidal controls, that is, cultural controls, should be used to a maximum extent or large quantities of insecticides may be needed. Many entomologists regard only the pink bollworm and lygus bugs to be the key pests in Arizona and southern California cotton-producing areas.

2. *Secondary (occasional) pests*.--These are species that are generally kept below damaging population levels by environmental controls, such as beneficial species and weather. Serious population outbreaks do not generally occur unless some upsetting event occurs. Most commonly this follows an insecticide treatment(s), which reduces populations of beneficial species to ineffective levels. A number of species belong in this category, including such important pests as the tobacco budworm, bollworm, cotton leafperforator, beet armyworm, cabbage looper, and several more.

3. *Potential pests*.--A host of species belong in this category, but they do not become pests under prevailing crop management systems or crop variety produced.

Comparatively little insecticide is needed for lygus bug control, but the large number of applications currently made for pink bollworm play an important role in determining the population levels of secondary pests. The repeated applications of insecticides applied for pink bollworm control soon decimate populations of beneficial species. If the insecticide applied is not effective on the secondary species--or if the latter has developed resistance to it--populations frequently increase rapidly to very serious populations. Such increases are widely recognized by farmers in the case of cotton leafperforator, tobacco budworm, bollworm, spider mites, and others. Experience has demonstrated repeatedly that the budworm and leafperforator can quickly destroy the crop. Occasionally, unexpected increases are noted of unusual pests. Two such species appeared in the Imperial Valley during the 1979 season. These were the Mexican mealybug and the bean thrips; very few people can even remember seeing the latter species on cotton before although it has rarely been recorded as a

pest in California. Occurrences of such unusual pests may be related to beneficial insect depletion; on the other hand, they may not reappear for years.

EFFECTS OF PINK BOLLWORM SPRAYS ON THE COTTON PLANT

Some insecticides have undesirable effects on cotton plant growth and fruiting (U.S. Department of Agriculture *1979*). This phenomenon has no relation to pest populations. The effect appears mainly to be a delay in fruiting of the cotton plant, which is followed by some acceleration in vegetative growth. Plants thus affected are taller than plants not receiving the application. Any delay in plant maturity is detrimental partly because the pink bollworm populations are larger, thus becoming more difficult to control as the season advances. Furthermore, succulent, lush plants are much more attractive to insects such as the tobacco budworm.

Not all insecticides exhibit the described effect on plant growth and fruiting; for example, the pyrethroid insecticides do not, but some of the organophosphorous insecticides do, particularly methyl parathion. The entire effect of the delay in fruiting in relation to final crop yield is not fully understood. The long production season in these two areas may permit the cotton plants to compensate for the delay in fruit set. Some believe, without supporting data, that yields are reduced, and some believe that boll size is reduced. Research underway should provide answers to these questions in another season or two.

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PINK BOLLWORM MONITORING METHODS

By N. C. Toscano and V. Sevacherian[1]

INTRODUCTION

The monitoring of insect populations within a cottonfield is a prerequisite for a pest management program. The presence and abundance of both pest and beneficial species must be determined before any rational control program can be initiated. There are cases where insecticides are applied blindly on a fixed schedule and the grower does not even know if the pest is present in the field. This practice is not only wasteful and costly, but it also leads to numerous problems. Thus, the first step in developing a pest management program is to develop rapid, practical, and accurate methods of assessing pest and beneficial population densities. This information is used to predict the damage potential and to determine the proper timing of pesticide applications. Monitoring methods have been developed for the major pests and for some of the lesser pests.

Many sampling methods are available for monitoring pink bollworm (Noble *1969*).[2] Generally, pink bollworm populations are sampled in two ways: by inspecting the crop environment or by using a device to trap or capture specimens.

VISUAL COUNT OR FIELD INSPECTION METHOD

The visual count method is the most commonly used procedure for determining insect population densities and their damage. Insects are counted and/or their damage is noted on a specified number of plants or plant parts. Thus, injury levels are established that are based on numbers of insects per given unit of measure, depending on the stage of fruiting or plant development.

Early infestations of pink bollworms can be detected in the blooms before bolls are present. Last stage larvae frequently web the petals together,

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 44.

forming a characteristic rosetted bloom that is easily seen. When firm bolls appear, these are the preferred sites for oviposition and larval feeding (Brazzel and Martin *1955*, *1957*; Toscano et al. *1979*), and the proportion of larvae in blooms declines drastically. Insecticide applications should not be initiated solely on the basis of infested blooms, but should be based on the degree of boll infestation.

Boll Inspection

In most field investigations of the pink bollworm, it is desirable to count boll infestations to estimate the larval population per acre. A count of pink bollworm exit holes in green bolls should not be used as an index to the abundance of the insect; the emerged larvae may represent only a small part of the population present. It is best to check for infestation only in 14- to 21-day-old bolls as these are the most susceptible to attack (Van Steenwyk et al. *1976*). The timing of insecticide applications based on exit holes may be too late, since a serious population buildup may occur before the treatment begins (Noble *1969*).

In general, samples should be taken once or twice a week. The sample area should be approximately 20 to 40 acres to assure reasonably accurate estimate of the pest or crop densities; however, where distinct ecological differences occur due to plant age, size, vigor, spacing, or culture, the field should be divided into sampling blocks that will reflect these differences.

A method of sampling bolls for pink bollworm infestation is to pick 25 susceptible bolls (14 to 21 days old) from each quadrant of the field. Select the bolls at random (one every four to five steps), starting at least 25 to 30 steps from the edge of the field. Crack and carefully examine a total of 100 bolls for first to fourth instar larvae in the lint or larval mines in the inner surface of the carpel wall. Mines, however, do not necessarily indicate an infested boll, because larval mortality is high when older bolls are attacked. Also, the absence of calluses or "warts" on the inner carpel wall does not necessarily assure the absence of a first instar larva, as calluses often do not form in younger bolls. Look carefully for any first instar larvae that may be present in the boll sample. Missing these smaller larvae in early season counts can often result in assuming infestation levels to be much lower than are actually present. Record the percentage of bolls infested.

Slosser and Watson (*1972*) found a direct relationship between the number of larvae per boll and percentage of bolls infested. Thus, it is much simpler to base infestation counts on the percentage of bolls infested. Studies by Adkisson et al. (*1963*) and Watson and Fullerton (*1969*) showed that at least 20 percent of the firm green bolls must be infested before control measures are warranted. During the latter part of the cotton-growing season, when a high proportion of bolls is open, much greater infestations can be tolerated without economic loss.

When it is desired to know the number of infested bolls per acre, the following procedure may be used:

The number of bolls per acre at the time the sample is collected may be estimated by counting 1 meter (about 40 inches) of row per 10 acres per field with a minimum of four counts per field. Each meter (40 inches) on a 40-inch row bed is approximately equal to 1/4,000 of an acre. Multiply each count by 4,000, take an average of these counts, and you have an estimate of the number of green bolls per acre in the field. This figure multiplied by the percent infested bolls equals the number of infested bolls per acre.

TRAPPING

Pheromone (Sex-Lure) Traps

For our purposes, let us define a pheromone as a chemical attractant emitted by an insect to attract the opposite sex of the species for the purpose of mating.

A variety of traps is available for monitoring moth activity. The simplest device to use is the pheromone trap. The use of this trap has made possible the successful establishment of a pest management program for some crops in the desert areas of California (Toscano et al. *1974*). It must be stressed here that this method has not been fully evaluated in other areas and may not be applicable for management of pink bollworms in all areas of the Southwest.

When growers properly use pheromone traps for several successive seasons, they usually experience the following benefits:

- Chemical usage is reduced because treatment and timing of treatment are based on actual need.
- Costs are reduced because less chemicals need to be purchased.
- Reduced chemical usage permits beneficial species to increase and contribute toward control of pests.

Insecticide applications based on counts of male pink bollworm moths will reduce the number of treatments by one-third to one-half, compared with the automatically scheduled weekly treatments made with no regard for the extent of infestations. Moth densities should be monitored daily with standardized pheromone traps, and treatments should be based on moth catches (Toscano et al. *1974*). The number of male moths trapped during a flight period helps to determine what control measures are needed. The seasonal trap catch total is used to evaluate and plan control measures from one year to the next.

A trap currently used in trapping pink bollworm males in southern California, for which a treatment index has been developed, consists of a cone-shaped cylinder with 16 holes for moth entry and a jar on the top, which traps the moths (Sharma et al. *1973*). The attractant chemicals for pink bollworm males are gossyplure (true pheromone) and hexalure (sex lure similar to pheromone).

The number of traps to be placed in a field depends on what use will be made of the catch data. To determine moth population densities in a field,

traps should be placed at the rate of one per 20 acres of cotton with a minimum of two traps per field. Traps placed to measure population levels can be used to measure control effectiveness and to spot population development trends.

Traps should be placed at a height that is level with the top of the cotton foliage. Trap heights must be adjusted periodically to maintain them at this level. The traps should be set at the start of the cotton-blooming period. Catches may be greater in the border traps where migrants are entering the field; therefore, place traps 50 yards into the field (Sharma et al. *1971*).

The interpretation of the trap catch data is greatly enhanced by daily monitoring. Tables and graphs of daily counts and accumulated totals of the season should be kept for year-to-year comparisons.

Traps should be serviced regularly to maintain their efficiency. The hexalure-impregnated wick should be changed every 15 days and gossyplure every 30 days. Optimum captures are obtained when the lures are dispensed from a 5/8- x 5/8-inch filter paper (Eaton and Dikeman No. 617) (Sharma et al. *1973*, Toscano et al. *1979*). Contamination of the trap can be avoided by not allowing the pheromone to drip from the filter paper onto the trap. The filter paper wick should be changed if it becomes contaminated with dust particles. Trapped moths, other insects, debris, and spider webs (which may block the opening into the jar on the trap) should be removed on each visit to ensure efficient trapping and accurate data.

There are some disadvantages to the use of the pheromone traps:

- Several other species of moths can be trapped along with, mistaken for, and counted as the pest moth.

- Maintenance and service can be a nuisance. If traps are not checked daily (preferably in the morning) and insecticides not applied within 24 hours, boll infestations may still occur.

- Catches may be affected by wind or rain.

- Pink bollworm is highly dispersive in late August and September, and the amount and time of the movement may vary between males and females. Since the pheromone trap monitors only male flight activity, estimating the female population with the trap becomes difficult late in the growing season.

In the early to mid-season when susceptible bolls are present, insecticides should be applied when a mean number of 3.5 to 4 moths per trap are captured with hexalure. When gossyplure is used instead of hexalure, the mean number of moths per trap needed to initiate a treatment also changes during the season. From June through July 15, a mean of 12 to 15 moths per trap is needed before an insecticide treatment should be applied. After July 15, revert to the 3.5 to 4 level. When a treatable number of moths is captured, insecticides should be applied within 24 hours and at night, if possible, to coincide with the moths' nocturnal activity.

Light Traps

Light traps containing argon bulbs or mercury vapor (black light fluorescent) bulbs will attract pink bollworm moths. Such traps may be valuable tools in monitoring infestations, seasonal abundance, and comparing yearly population trends. The argon trap is generally used in pink bollworm surveys because it is more selective than the black light (Noble *1969*). Although it attracts smaller numbers of pink bollworm moths, the collection of orders other than Lepidoptera is decreased, and, thus, the argon trap reduces the time required for examining the collections.

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COTTON CULTIVARS RESISTANT TO THE PINK BOLLWORM

By F. D. Wilson[1]

INTRODUCTION

Investigations of natural resistance in cotton to pink bollworm, particularly by State and Federal workers at the Texas Agricultural Experiment Station, about 1937-62 (Noble *1969*),[2] provided the foundation for a major effort in Arizona, launched in 1971 (R. L. Wilson and Wilson *1979*).

In short-staple cotton, *Gossypium hirsutum*, two major types of germplasm have been screened for pink bollworm resistance--upland variants and primitive races (Texas race stocks). The former include visible morphological mutants and cottons differing more subtly from currently grown upland cultivars. The latter include both photoperiodic (short-day flowering) and day-neutral stocks. In long-staple cotton, *G. barbadense*, both morphological mutants and obsolete cultivars have been screened.

To measure seed damage by pink bollworm, a sample of 300 to 500 seeds is X-rayed, and the percentage of damaged seeds is calculated (R. L. Wilson and Wilson *1975*). Percentages of seed damage to check cultivars grown at Tempe, Ariz., 1974-77, are presented in table 1.

The several *G. hirsutum* variants that have shown less seed damage than the checks are discussed below; seed damage and yield data are presented in table 2. Of those listed in table 2, only nectariless and nectariless-glabrous cultivars and a moderately early cultivar are immediately useful because they have lower seed damage but yield as much or more lint than check cultivars and are comparable in fiber quality. The other upland variants and the Texas race stocks usually have not yielded as much lint as the checks and some suffer from other agronomic and fiber-quality deficiencies. The *G. barbadense* (Pima) mutants with less seed damage usually also yielded less lint than the checks, with the possible exception of Pima Okra-leaf. None of the individual mutants or strains has a high enough level of resistance to stand alone. Their main value will be as components of integrated pest management systems and as breeding stocks to combine resistance characters.

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[2] The year in italic, when it follows the author's name, refers to Literature Cited, p. 50.

Table 1.--*Seed damage by pink bollworm to check cultivars of* G. Hirsutum *and* G. barbadense *grown at Tempe, Ariz., in unsprayed plots, 1974-1977*

Cultivar	Seasonal seed damage[1]			
	1974	1974	1976	1977
	Percent			
Deltapine 16	6.5-11.6	19.1-45.8	23.2-42.4	6.6-10.6
Deltapine 61	---	---	60.2	6.8
Stoneville 7A	8.3-13.1	19.6-37.5	25.8-44.0	8.3-10.1
Stoneville 213	---	---	36.8-39.0	15.5
Stoneville 256	---	---	54.1	7.0
Pima S-4	9.6	---	---	---
Pima S-5	---	44.9	44.5	14.8

[1] All data are means of 4 replications and 4 or 5 harvests, except in 1974, when seed cotton was harvested only once for estimates of seed damage; 2 means for a given cultivar/year combination represents the range of means over several tests.

Note: Dashes indicate no data.

NECTARILESS AND GLABROUS

According to R. L. Wilson and Wilson (*1976*, *1977a*), two nectariless, hirsute cotton cultivars have been released ('Stoneville 731N' and 'Stoneville 825N') and nectariless, glabrous breeding stocks are in advanced stages of development. Nectariless cotton has yielded as much or more lint than the check cultivars in unsprayed plots. One nectariless-glabrous breeding stock outyielded the check in one test, and another one yielded slightly less lint in one test but substantially more in another.

Nectariless cotton reduces the food available for pink bollworm moths. One hectare of normal, nectaried cotton has an estimated 22 to 24 million feeding stations for the insects (R. L. Wilson and Wilson *1977a*). The resistance mechanism of the glabrous character is not known, but glabrous cotton is probably nonpreferred by the female moth.

The nectariless-glabrous combination in one background, La 15213, reduced seed damage 57 percent below that of the check, which could be a self-sufficient level of resistance unless pink bollworm damage were very high. Other nectariless, glabrous combinations have not shown this level of resistance (table 2).

Table 2.--*Seed damage by pink bollworm and lint yield (as percentages of check cultivars) in resistant cotton strains and cultivars grown at Tempe, Ariz., in unsprayed plots*

Cotton strain or cultivar	Character(s) tested[1]	Year(s) tested	Seed damage		Lint yield	
			Low	High	Low	High
			Percent of check			
Stoneville 731N	Ne	1975-77	54.8	76.9	98.7	117.0
Stoneville W74-4-153	Sm	1975	79.6	79.6	93.5	93.5
Stoneville La 15213	Ne, Sm	1975	43.1	43.1	108.4	108.4
Deltapine 7146N	Ne, Sm	1976-77	56.3	86.3	89.1	149.5
Deltapine TM-1(H_2)	Pilose	1974-75	38.4	64.7	[2]88.3	[2]88.3
Stoneville La Okra-2	Okra-leaf (L°)	1976-77	79.6	88.0	86.4	95.1
Arizona Super Okra	Super Okra leaf (L^{S})	1976-77	61.1	62.1	60.8	72.1
ORS-13	Sm, L°, frego (fg)	1976-77	55.0	64.7	59.4	71.1
1x6-56	Extreme earliness	1975-76	43.3	62.3	42.9	48.7
(1209x407-38)	Moderate earliness	1975-76	55.9	63.5	77.4	85.3
DES 2134-056	Slight earliness	1975-76	84.2	85.9	99.2	121.4
AET-5	(Unknown)	1974-77	58.5	70.0	64.1	108.1
HG 6-1-N	High gossypol	1976-77	62.8	78.6	64.8	74.5
Pima glandless	Glandless	1974-77	68.3	97.3	76.8	89.7
Pima Okra	Okra-leaf	1974-75	81.3	92.9	[2]104.5	[2]104.5
Pima pilose	Pubescence	1975	86.0	86.0	[2]62.3	[2]62.3

[1] Ne, nectariless; Sm, glabrous.
[2] 1975 only.

EARLINESS

According to R. L. Wilson et al. (*1979*), seed damage has usually been lower in early maturing cottons than in check cultivars [earliness is herein defined as the percentage of total seed cotton harvested at the first of several (usually four or five) biweekly harvests], presumably because of escape. Unfortunately, most early maturing cottons yield significantly less lint than full-season cultivars in the southwestern deserts. Moderately early strains, such as 2134-056, that reduce seed damage and also yield well, may be particularly valuable in integrated control and as breeding stocks in the development of cultivars with multiple resistance characters (table 2). Other early maturing cultivars may also be valuable in the future, not only to control pink bollworm but also to reduce other production costs.

OTHER UPLAND VARIANTS

The other upland variants that have shown reduced seed damage by pink bollworm are pilose (densely pubescent; Smith et al. *1975*, R. L. Wilson and Wilson *1977b*), Okra-leaf and Super Okra-leaf (R. L. Wilson et al. *1979*), high gossypol content (R. L. Wilson et al. *1979*), and several breeding stocks of complex parentage collectively designated as AET- (R. L. Wilson and Wilson *1977b*). None of these stocks seems to have the yield potential of the check cultivars, but some approach it, notably La Okra-2 (Stoneville 7A Okra-leaf) and AET-5 (table 2).

Densely pubescent cultivars are not useful in the United States and other areas where cotton is harvested mechanically because they contribute too much trash to the seed cotton. In other areas of the world, where jassids and pink bollworm are both important pests, dense pubescence may be advantageous. Unfortunately, the pilose gene, H_2, has a pleiotropic effect on fiber quality and is therefore of no practical value. Other pubescence genes are available in cultivars currently grown in jassid areas.

At least part of the resistance shown by Okra-leaf and Super Okra-leaf variants is attributed to escape because these cottons are also early maturing. The more open leaf canopy of these mutants provides a warmer and drier microenvironment and could conceivably affect insect behavior and development.

The high-gossypol breeding stock HG-6-1-N unexpectedly showed less seed damage than the checks (table 2). Strains with high-gossypol content screened earlier showed no pink bollworm resistance (R. L. Wilson and Wilson, unpublished).

The mechanism of resistance in the AET- stocks has not been identified. If we could identify it, or at least if we could establish a workable selection scheme to identify resistant plants in segregating progenies, then these stocks would be valuable in the development of multiple-resistance cultivars.

TEXAS RACE STOCKS

About 300 race stocks have been screened for pink bollworm resistance in Arizona and Puerto Rico. About 20 percent have been selected. The most useful of these will probably be the day-neutral *latifolium* types (that is, those most closely related to upland cultivars). For the most part, however, the race stocks are inferior agronomically and in fiber properties to currently grown cultivars. Transferring resistance from these sources will require a long term breeding effort (F. D. Wilson and Wilson *1975a*, *1978a*, *1978b*; R. L. Wilson et al. *1979*).

LONG-STAPLE VARIANTS

According to Wilson et al. (*1977*), Pima glandless, Pima Okra-leaf, and Pima pilose have shown reduced seed damage from pink bollworm, at least in some tests. Pima Okra-leaf also yielded as much lint as the check cultivar in a 1975 test (table 2). Pima nectariless, now under development (E. L. Turcotte, personal communication), will represent a valuable addition to our resistance arsenal if it behaves in the same way as short-staple nectariless. Okra-leaf nectariless is a realistic combination in long-staple cotton that could possibly enhance resistance.

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POTENTIAL OF STERILE MOTH RELEASES FOR PINK BOLLWORM MANAGEMENT

By T. J. Henneberry[1]

INTRODUCTION

Research was begun in 1961 (Ouye et al. *1964*)[2] to determine the potential of applying the sterile insect release method for control of low-level field populations of the pink bollworm, *Pectinophora gossypiella* (Saunders).

The promising early results of Ouye et al. (unpublished data) and Richmond and Graham (*1970*, *1971*), as well as the spread and establishment of infestations in southern California cotton-growing areas, prompted the initiation of a sterile pink bollworm release program in the San Joaquin Valley of California by the USDA Animal and Plant Health Inspection Service (APHIS) and the California Department of Agriculture with the objective of preventing the insect from further spread into that uninfested area. No sterile release program, except on a research basis, has been initiated to suppress established pink bollworm infestations. Bartlett (*1978*) recently reviewed the literature concerning the subject.

At present, the pink bollworm remains the key pest in the southwestern desert cotton-growing areas of Arizona, southern California, and northern Mexico with the continued threat of spread into northern California. In the infested areas, scheduled applications of insecticides are often required for control with the attendant problems of resistance, destruction of nontarget organisms, and induced secondary pests. A selective method of pink bollworm control is a prerequisite for the development of a cotton pest management system in areas where it is a pest. The sterile insect release method (SIRM) has been suggested as a possible technique for integration into a pink bollworm management system. The present paper will briefly review this method with particular references to its potential for pink bollworm control.

STERILE INSECT RELEASE METHOD

The concept of using insects for their own destruction via sterile insect release systems was conceived in 1937 by E. F. Knipling (Bushland *1971*). The

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 63.

resulting method involves mass rearing of the subject insect, induction of sexual sterility, and release of large enough numbers to provide sufficiently high ratios of sterile-to-native insects to induce a downward trend in the field population. Thus, most matings involve released sterile insects and native insects; thereby, the reproductive potential of the native population is reduced proportionately.

Knipling (*1964*) calculated that when 90 percent of the total insect population in the first generation consists of released sterile insects and the same number of sterile insects is released each subsequent generation, the native population may be eliminated by the fourth generation, assuming an average fivefold increase rate per generation for a native population. In contrast, a program of control with insecticides that kill 90 percent of the insects in each generation would theoretically require more than 10 generations to eliminate the population. Moreover, if a nonselective control method is used and the natural biotic agents are reduced in numbers, the increase rate of the pest may exceed the suppression due to the chemical treatments.

Initial releases of sterile insects must produce high enough ratios of sterile-to-native insects to start a downward trend in the population. Thus, populations of most pest species must be reduced considerably by other means before a sterile insect release program will be feasible. The optimum time to begin a program of sterile insect releases is when the active native population is at its lowest level. The proper timing for all releases must be critically and exactly determined.

A sterile insect release program will be effective only when the reproductive potential of the total population or a large segment of it is suppressed; thus, the migration of native insects into the control area can be greatly reduced or prevented. Much information must be provided before a reasonable probability of a successful sterile insect release program can be assured.

MASS REARING PINK BOLLWORMS

One of the major prerequisites leading to the application of SIRM is the available technology to rear for release millions of the target insect species. Pink bollworm laboratory rearing on artificial diet was originally accomplished in individual containers with a single insect per container (Beckman *1953*, Vanderzant and Reiser *1956*). A major breakthrough was the development of a technique using physical barriers between layers of diet, allowing pink bollworm larvae to be reared in mass (Richmond and Ignoffo *1964*). Using this concept, Mangum et al. (*1969*) modified and expanded pink bollworm rearing to the point of producing a million or more sterile insects for release per week.

Pink bollworm mass-rearing methods have been continually improved. At present (1979), the APHIS facility at Phoenix has consistently produced in excess of a million moths per day available for sterile release purposes for about $3 per thousand insects (L. A. Stevens, personal communication). Further, extensive research and development to mechanize and improve the system would probably increase rearing capability at reduced costs.

SIRM focuses on applying control pressure to the total insect population rather than to small local infestations. If such a program were initiated to suppress pink bollworm populations in the southwestern cotton-growing areas of the United States, the numbers of moths needed would be greatly influenced by the geographical area involved and cotton acreage grown as well as the population density and migratory behavior of the insect.

The pink bollworm-infested areas of concern in such a sterile insect release program include Arizona, Arkansas, California, Louisiana, New Mexico, Nevada, Oklahoma, and Texas (U.S. Department of Agriculture *1977*). Infested areas also exist in cotton-growing areas of northern Mexico adjacent to the States listed above. The cotton-growing areas in Arizona, California, and northern Mexico have high pink bollworm population densities. Published reports indicate that pink bollworm moth emergence from overwintering larvae ranges from a low of 395 per ha under strict cultural control conditions (Watson et al. *1974*) to a high of over 83,980 per ha with minimal attempts to impose high mortality with cultural practices (Bariola et al. *1976*).

About 405,000 ha of cotton are grown in the heavily infested areas described; thus, the possibility of achieving rearing production with existing facilities that would produce enough sterile pink bollworms for effective sterile pink bollworms for effective sterile-to-native insect release ratios appears remote. A combination of area-wide cultural and/or other control methods would have to be put into practice to reduce native pink bollworm populations to low levels before the sterility method can be considered as practical for management of established infestations in the areas described.

Assuming that such methods reduce populations to low enough levels in the defined geographical area, the migratory potential of pink bollworm moths must also be considered. Late-season migrations of pink bollworms of up to 65 miles have been well documented (Ohlendorf *1926*, McDonald and Loftin *1935*, Noble *1969*). In addition, migrating pink bollworm moths from overwintered larvae have been demonstrated to initiate infestations in cotton isolated 35 miles distant from the nearest source of infestation (Bariola et al. *1973b*). Thus, careful consideration must also be given at least to the low pink bollworm population density areas of Nevada, New Mexico, and Texas, and possibly Arkansas, Louisiana, and Oklahoma since it appears fairly well documented that male pink bollworm moths migrate from the Imperial Valley of California to the San Joaquin Valley several hundred miles away (Stern and Sevacherian *1978*).

One of the most important contributions of the southeastern screwworm sterile release program (Baumhover *1966*) applicable to large-area insect suppression programs, involving migrating insect species, was the development of the "barrier" concept in which a buffer zone of sterile insect releases is established adjacent to the core eradication zone to prevent immigrants into the latter area. The necessity for such a suppression barrier zone to prevent or minimize infiltrating pink bollworm moths will have to be considered in any sterile pink bollworm release program in the United States and, possibly, as a continuing long-term program to prevent infestation from migrating pink bollworms from Mexico. The possibility of joint action by Mexico in area-wide management of the pink bollworm should be considered. This would increase the chances of success and no doubt reduce management costs for cotton grown in the United States.

RADIATION-INDUCED STERILITY

Radiation treatment of immature stages of the pink bollworm to induce sterility and obtain moths for release would be particularly desirable for ease of handling as compared with radiation of adults. However, irradiation of pink bollworm eggs (Wolfenbarger and Mangum *1972*, Bartlett et al. *1973*) or larvae (Bartlett and Lewis *1973*) have not been promising because of mortality and/or adult deformities or reduced mating of resulting adult insects.

Ouye et al. (*1964*) demonstrated that pink bollworm pupae exposed to 25 krad or more of gamma radiation produced sterile adult moths. Age of pupae at the time of treatment was critical, and exposure of younger than 5- to 7-day-old pupae resulted in excessive mortality and adult malformations. The difficulty in obtaining large numbers of pink bollworm pupae at the precise required age using the available pink bollworm mass-rearing techniques (Richmond and Ignoffo *1964*, Mangum et al. *1969*) necessitated adult treatment. Subsequently, Graham et al. (*1972*) found that newly emerged male adults exposed to doses of gamma radiation of 5, 10, 15, or 20 krad and outcrossed to untreated females were 42, 62, 91, and 98 percent sterile, respectively. F_1 progeny outcrossed to untreated insects were over 99 percent. Matings of males and females exposed to doses as low as 5 krad were nearly 80 percent sterile and produced no fertile F_1 progeny. Inherited sterility was lost rapidly in F_2 and later generations. Cheng and North (*1972*) reported similar results as did LaChance et al. (*1973*).

Although the theoretical advantages of releasing partially sterile insects appear promising, the contribution of F_1 sterile pink bollworm progeny in suppressing populations has not been clearly documented. The results of Flint et al. (*1974*, *1975*) in field cages, however, indicate that 10-krad treated pink bollworm moths were more effective than released moths exposed to higher doses of radiation. Furthermore, R. L. Staten (personal communication)[3] obtained effective suppression and control of pink bollworm populations under field conditions by releasing 10-krad treated moths.

Klassen and Creech (*1973*) examined the potential of partial sterility and conditional lethal mutation in suppression programs. They showed that the rate of insect population increase determines the effectiveness of combinations of levels of male sterility and release ratios. For example, population increases of fivefold can be effectively started downward with 90-percent sterile insects where populations increasing at a rate of tenfold per generation require virtually 100-percent sterile insects, in each case at 12.5:1 sterile-to-untreated insect release ratios.

These authors also developed a model based on the data of Graham et al. (*1972*). They assumed 5- or 10-krad treated pink bollworm moths were fully competitive with native insects in mating, native populations increased tenfold per generation, and the overwintering generation could be reduced to 247 per ha with cultural and other control measures. Simulated populations of 5-krad

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[3]Staten, R. L., Brazzel, J. R., Bartlett, A. C., and Robinson, G. D. Suppression of a native pink bollworm population through releases of mass-reared, partially sterilized moths. Unpublished report, USDA-APHIS.

treated males released at a ratio of 19:1 in the first and third generations only gave effective control, whereas release ratios of 39:1 provided total suppression at a cost of $20 and $40 per ha, respectively. Rearing and release costs were estimated to be $3.40 per 1,000 insects. Mixed-sex sterile releases of 10-krad treated moths, also containing the conditional lethal for nondiapause at 24:1 or 29:1 ratios every other generation, resulted in maintaining a static population during the season, but the overwintering generation was less than one insect per hectare. The cost of the programs was about $37 and $45 per ha, respectively.

The more recent data of Bartlett and Butler (In press, *1980*) indicate that the few F_1 progeny from irradiated (15 and 20 krad) female parents mated to untreated males were more than 90 percent sterile, but their results with 10-krad treated females were similar to those of Graham et al. (*1972*). The authors showed that when sterile males or sterile females were crossed to untreated insects--or when males and females, treated with 10 krad, were mated--population growth was reduced 82.6 to 99.9 percent over two generations as compared with a simulated untreated population development.

CAGE AND FIELD STUDIES WITH STERILE PINK BOLLWORM RELEASES

The results of six field cage experiments to evaluate sterile pink bollworm moth releases for suppressing untreated populations have been reported. A brief summary of the results of these studies is shown in table 3. In addition, five large-scale experimental field trials have been conducted to determine the feasibility of suppressing established pink bollworm field infestations. The results of the field cage tests have varied considerably ranging from 95 percent (Richmond and Graham *1970*) to 16 percent (Bariola et al. *1973a*) reduction of the untreated populations. The amount of suppression obtained following sterile moth releases was not reported by Ouye (personal communication).

Several field experiments have also been conducted to evaluate the impact of sterile pink bollworm releases on established infestations. Bartlett (*1978*) reported that J. C. Keller (unpublished data), in a partially isolated area near Humbolt and Rim Rock, Ariz., obtained approximately 64 percent reduction of pink bollworm population development under field conditions by release of sterile pink bollworm moths obtained from 10-krad treated pupae. Sterile-to-native moth release ratios were estimated to be 20:1, and the experiment was conducted over five generations of the insect. The probability of considerable emigration of released insects, as well as immigration of normal native insects into the study area, must be taken into account in appraising the results of such experiments. Such movement of insects can result in an underestimate of the true effectiveness and potential of the sterile insect or any other suppression technique.

A sterile pink bollworm (25 krad) moth release experiment was conducted in a 2-ha cottonfield at Borrego Springs, Calif., in 1969 (Graham *1978*). Cotton grown in the field the previous year had been heavily infested with pink bollworm, but overwintering mortality was high.

Table 3.--*Results of field cage experiments to evaluate sterile moth releases for pink bollworm control as reported by various authors*

Source	Radiation dose (krad)	Sterile-to-native ratio generation		Control achieved as percent of check generation[1]	
		1	2	1	2
Ouye et al. (*1964*)	([2])	([2])	([2])	([3])	([3])
Richmond and Graham (*1970*)	25	[4]50:1	None	[5]95	[5]91
	40	50:1	None	[5]87	[5]72
Richmond and Graham (*1971*)	15	25:1	55:1	[5]67	[5]81
	25	25:1	58:1	[5]69	[5]85
Bariola et al. (*1973*)	10	20:1	([2])	21	([2])
	10	50:1	([2])	16	([2])
Flint et al. (*1974*)	10	13-20:1	([2])	34	[5]68
	20	13-20:1	([2])	0	44
Flint et al. (*1975*)	10	100:1	10:1	[5]86	([2])

[1]Total for season as calculated from author's data.
[2]Not reported.
[3]Suppression.
[4]Single release at initiation of experiment.
[5]Significantly different from control cage populations.

A sterile-to-native ratio of 50:1 was estimated to be essential to reduce the field populations, assuming no migratory moths entered the area (the field was 40 to 50 km from the nearest cotton in the Coachella and Imperial Valleys, respectively). Releases of moths treated with 20 krad were begun June 6, 2 days after the first pinhead squares were found. The desired ratio of sterile-to-native moths was not reached until June 27 and was maintained only 3 weeks. The sterile moth releases failed to suppress the native population. Immigration of pink bollworm moths from the Imperial Valley of California, about 48 km away, was reasonably established on the basis of unaccounted for high hexalure trap catches correlated with wind direction and movement from the Imperial Valley and was undoubtedly responsible for the declining sterile-to-native moth ratio. APHIS personnel conducted a similar pink bollworm sterile release program in the Coachella Valley, Calif., in 1969 with similar results (R. L. Staten, personal communication).

As previously noted, the effect of infiltrating native moths from distant heavily infested areas into small cotton-growing areas readily occurs. This was clearly shown by the data obtained by Bariola et al. (*1973b*) in a small cotton planting of about 1.6 ha, approximately 56 km from heavily infested cotton in the Imperial Valley. No cotton had been grown near the newly planted area for some years; however, considerable numbers of pink bollworm makes were captured in hexalure traps early in the season, and larval infestations due to direct immigrants were readily detected.

In 1970, a second experiment was conducted in the same area (Borrego Springs) with sterile moths obtained from 10-krad irradiated pupae (Bariola et al. *1973a*). Effective overflooding ratios were not achieved, but 13 percent of 39 male larvae collected had chromosomal aberrations, whereas none were found in larvae collected in fields where sterile moths were not released. Since released moths were 85- to 90-percent sterile, the collected larvae could have been F_1 progeny of released insects; however, the authors suggested that they were more probably the result of released sterile insects mating with native moths, which in any case indicated that the released moths did mate with the native population.

In 1971 and 1972, the Moapa Valley in southern Nevada was selected by APHIS personnel as an experimental area to evaluate the potential of 10-krad, partially sterilized pink bollworm releases for suppressing a field population of the insect (R. L. Staten, personal communication). Results indicated as great as a fivefold reduction of fertile progeny in release vs. nonrelease fields and significant decreases in moth populations in sterile release fields.

The pink bollworm has existed in wild cotton in southern Florida since its discovery in 1932. A sterile (15 krad) pink bollworm moth release program was initiated in 1968 by APHIS personnel and continued until August 1976 in wild cotton on the Florida Keys. During this period, infestations remained at low levels, indicating suppression of the population (U.S. Department of Agriculture *1977*). Pink bollworm infestations have not increased significantly since termination of the sterile moth releases.

Large-area, field-type experimentation to evaluate the impact of sterile pink bollworm moths releases has been frustrated by lack of isolation. Migrating moth populations in two of the studies apparently masked the effects of sterile release insects and prevented evaluation of the program. In the Moapa Valley tests, migrating populations were not a serious limiting factor, and significant reduction in the native populations was obtained. The effect of migrating insect populations on large-area population suppression programs has been difficult to assess. Prout (*1978*) indicates that sterile releases cannot effectively reduce adult populations if the rate of infiltration is high. Results obtained in at least two field release trials, already discussed, fully support this conclusion.

The feasibility of releasing sterile or genetically altered insects to slow down normal population growth rates rather than to reduce or eradicate populations has been given relatively little consideration as a component of a pest population management system. If economic damage by a pest in certain areas is due primarily to immigrating insects from a more favorable overwintering area each year, the release of sterile insects in the area to be protected to prevent the development of economic populations before the end of a crop season could provide a practical and ecologically acceptable pest management system. Given the dynamics of a pest like the pink bollworm or *Heliothis* species, the release of enough sterile insects each generation to merely reduce the growth rate of an immigrant population by an average of one-half of normal would theoretically reduce a fourth generation population by 87.5 percent (E. F. Knipling, personal communication). The same result could also be expected from low-level overwintered populations, when economic control rather than eradication would be the objective.

PINK BOLLWORM STERILE RELEASES TO PREVENT ESTABLISHMENT OF POPULATIONS IN UNINFESTED AREAS

A specialized use of sterile pink bollworm moths developed as a result of the first occurrence and subsequent established infestation of the insect in the Imperial Valley of California in 1965. Spread of the insect throughough Imperial, Riverside, and San Diego Counties was very rapid, with severe losses occurring by 1967. Infestations were detected in the high desert areas of Los Angeles, San Bernardino, and Kern Counties in 1967. Four moths and six larvae were found in the San Joaquin Valley south of Bakersfield in late 1967. Thus, threat of establishment of economic populations in the San Joaquin Valley from migratory moths resulted in the initiation in 1968 of sterile pink bollworm releases in Kern County to prevent infiltrating insects from becoming established in the Valley (U.S. Department of Agriculture *1977*).

Release moths were exposed to 40 krad in 1968, 30 krad in 1969, 25 krad during the 1970 and 1971 seasons, and 20 krad from 1972 to 1977. These dosages have been continually adjusted downward with increasing amounts of research information, indicating better field performance of the released insects sterilized at lower doses (Graham et al. *1972*, Richmond and Graham *1970*, *1971*); however, with releases of 1 to 6 million moths per day in the area, some boll infestations might occur if insects were treated with less than 20 krad (Flint et al. *1977*). Although low-level infestations resulting from released moths may be of no economic significance, such infestations can be confused with infestations due to normal moths.

In 1968, about 9 million moths were released in the San Joaquin Valley. The program has expanded each year, and in 1977 over 400 million moths were released. Annual ratios of release-to-native moths as measured by pheromone traps have ranged from about 100:1 to 6,200:1 (U.S. Department of Agriculture *1977*).

An analysis was made of the native and sterile male pink bollworm trap capture date obtained for the San Joaquin Valley during the 1977 season.[4] From June 13 to July 16 (first generation) released sterile males captured in gossyplure-baited trapes indicated an overall sterile-to-native moth ratio of 173,000:1, which should assure that no reproduction would occur by a low and widely scattered overwintered native population even if the released sterile males were no more than one percent competitive. Furthermore, such high ratio of released-to-native moths should assure little or no reproduction, if males are completely noncompetitive, but the released females are comparable to native females in attracting native males.

E. F. Knipling (unpublished report), using the Lincoln Index Method of estimating animal population numbers in an analysis of the 1977 APHIS pink bollworm moth trap catch data, calculated a native male pink bollworm popula-

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[4] Knipling, E. F. A critical analysis of the pink bollworm suppression program in the San Joaquin Valley, California. Unpublished report, U.S. Department of Agriculture, Science and Education Administration-Agricultural Research.

tion of about 150 insects in the San Joaquin Valley during the period corresponding to the first field generation. Some or even most of the males captured during the first generation period may have been immigrants rather than overwintered survivors.

In view of the low native population and the high ratio of sterile released-to-native males, Knipling concludes that there was little or no reproduction due to overwintered moths in the San Joaquin Valley during 1977. The capture of larger numbers of native moths during subsequent generations was attributed to direct immigrants from other distant infested areas and the progeny of previously mated female immigrants. He also pointed out that the first opportunity for sterile males to inhibit reproduction of mated female immigrants will be the progeny of such immigrants. Therefore, the program in the San Joaquin Valley, in effect, must be regarded as a suppression rather than an eradication program.

The trap capture data indicated that the ratio of sterile-to-native moth was 2,500:1 during generation 2 despite the evidence of strong infiltration of native moths. The overall ratio of sterile-to-native moths was about 200:1 during generation 3, and 50:1 during generation 4. Sterile-to-native moth ratios of this magnitude should greatly reduce reproduction of unmated female immigrants or the progeny of previously mated immigrants. At present, there is no method of conclusively verifying the degree of suppression produced by the sterile moths. This would apply for any method of control that might have been used. Prout (*1978*), using computer simulation modeling techniques, concluded that releasing sterile males for pest population suppression cannot reduce adult populations if immigration of previously mated females is appreciable; however, the rate of infiltration into the San Joaquin Valley in terms of the number of sterile moths released is very low judging from the ratio of sterile-to-native males captured in traps. Prout (*1978*) was unable to estimate the levels of immigration a sterile male release program can tolerate when immature stages of the insect are the most important economic consideration. The present gossyplure trap monitoring systems provide information on male pink bollworm populations. The number of migrating females and their mating status is unknown.

Each year since the initiation of the program, native pink bollworm moths have been captured in the valley. These are assumed to be mostly migrant males since the insect is known to travel long distances (Bariola et al. *1973b*, Graham *1978*, McDonald and Loftin *1935*, Ohlendorf *1926*, Stern and Sevacherian *1978*). In 1976-77, however, it was demonstrated that sterile diapause larvae survived and pupated, and adults emerged in the Bakersfield, Calif., area (A. C. Bartlett, personal communication).

Since no established infestation has occurred irrespective of moth migration into the valley and proven ability to overwinter, and the trap and monitoring data show high ratios of released-to-native moths, there appears to be a sound basis for assuming that the sterility method has been highly successful. Also, there has been no evidence of large localized native populations before the end of the cotton-growing season, despite indirect evidence of substantial immigration of moths from distant infested areas during the regular growing season. The only way to conclusively prove that the assumption of a successful program is correct would be to terminate the sterile release program to compare pink bollworm infestation trends with those observed during the years of release. In view of the risk involved, a more logical and reasonable approach

appears to be continued research effort to analyze and evaluate the insects released, their interaction in the population, and to undertake suitable pilot programs to determine their impact on migrating pink bollworm populations, as well as on low-level established field infestations.

FACTORS AFFECTING THE EFFICIENCY OF STERILE PINK BOLLWORM MOTH RELEASES

The sterile release method involves rearing, irradiation, and release of the target species. Reduced field effectiveness of the laboratory-reared, irradiated, and released insect may be attributed to alterations induced during any one or a combination of these activities. Reduced competitiveness of laboratory-reared, sterile pink bollworm moths has been manifested in reduced longevity from moths obtained from irradiate pupae (Ouye et al. *1964*) and irradiated (20 krad) adults (Cheng and North *1972*), and need for sterile-to-untreated moth ratios in excess of theoretical values to achieve reductions in population increases (Bariola et al. *1973a*; Flint et al. *1974*, *1975*; Graham *1978*; Richmond and Graham *1970*, *1971*).

It is difficult to separate the effects of behavioral changes, radiation treatment, laboratory rearing, handling techniques, domestication, and the nature of the diet on field performance of the released insects. Cheng and North (*1972*) and LaChance et al. (*1973*) found no effect of radiation (5 to 20 krad) on sperm transfer in laboratory-reared adult males. The number of spermatophores per mated female, however, increased when females were mated to males exposed to 20 krad, indicating that females were more receptive to repetitive mating. Females mated to males lacking the ability to effectively inseminate them tend to mate more frequently (Cheng and North *1972*); however, if the sterile-to-native ratio remains at a high level, the probability of a second mating with a sterile insect should remain the same as in the case of the initial mating and may not be a consideration of critical importance. Further, irradiated laboratory-reared female pink bollworm moths, an important consideration in the pink bollworm sterile release system, were reported to be as attractive to native males as untreated females in the field, and irradiated females (5 to 40) krad mated as readily as untreated females, but had significantly reduced ability to transfer sperm to the spermatheca (Flint et al. *1973*). If the ratio of released-to-native insects is at levels up to 50 or 100:1, released females may achieve adequate suppression even if males are virtually noncompetitive provided the females are reasonably competitive with native females in attracting native males for mating.

LaChance et al. (*1975*) studied the reproductive performance of untreated and irradiated laboratory-reared and native pink bollworm strains to compare the effects of colonization and irradiation on the insects. Although the mating frequency of males of either strain was similar, native males transferred normal amounts of eupyrene sperm more frequently than laboratory-reared males. The diet of laboratory-reared males may be a factor that has not been adequately investigated.

Laboratory-reared pink bollworms have not compared favorably with native insects when measured by several other criteria. For example, Flint et al.

(*1975*) found that native pink bollworm moths as measured in flight mill tests were more active than laboratory-reared or laboratory-reared and irradiated moths, but no difference occurred between laboratory-reared, irradiated, or untreated moths. The reason for this difference in vigor should be one of the important areas of investigation in order to improve overall vigor. Bariola (*1978*) reported further evidence of the lack of performance of laboratory-reared pink bollworms in that their rate of reproduction in field cages was only one-tenth that of native overwintered moths; however, there would seem to be no reason why laboratory-reared insects can not be produced that are equal to or even superior to native-reared insects. In-depth research in appropriate scientific discipline areas is needed to attain this goal.

CONCLUSIONS

Mass-rearing capability for producing large numbers of pink bollworm moths has improved dramatically in recent years. Increased research efforts to mechanize many of the steps in the rearing protocol could undoubtedly increase efficiency and production at reduced costs.

Native pink bollworm populations in southwestern cotton-producing areas are extremely high and would have to be reduced to low levels using a combination of cultural and other control methods before SIRM can be considered practical for further suppression or for continuous management. The technology for achieving a very high degree of suppression of native population is well advanced, however, and may be well within the range of practical feasibility if the industry is prepared to make use of available technology for 1 or 2 years in a thorough and fully coordinated manner.

Ionizing radiation-induced sterility in pink bollworm moths for release can be achieved at dosage levels (10 to 25 krad) that result in minimal or no effect on longevity or mating of the insects. Radiation doses as high as 40 krad do not result in complete sterility; however, a high degree of sterility occurs in F_1 progeny produced by parents exposed to doses as low as 5 to 10 krad. The potential, theoretical advantages of releasing partially sterile pink bollworm moths must be carefully considered as a compromise between acceptable levels of infestation as a result of the sterile F_1 generation that will be developed in the cotton crop and the projected contribution of the sterile F_1 progeny in reducing the reproduction potential of the native population. Infestations due to partial fertility, however, should be well below acceptable levels if the native population has been reduced to the degree necessary to make it practical to release the number of moths required for further suppression or to prevent the growth of economic populations.

The biological significance (1) of a reduced ability to effectively inseminate females, (2) of transferring eupyrene sperm by sterile-released males or their progeny, and (3) of effects on reproductive behavior of involved females have not been defined in cage or field tests but affect the efficiency of sterile releases for control or suppression of pink bollworm populations.

Colonization and laboratory-rearing procedures may have resulted in gradual selection of less vigorous and behaviorally different strains affecting field

performance of released insects interacting with native populations. Other factors, such as nutritional deficiencies, may also be involved. The importance of and the reasons for less than the expected impact of sterile releases on population development has not been fully determined and should be fully investigated with a view to the production of insects that are as close to normal vigor and competitiveness as possible.

The APHIS sterile pink bollworm release program, designed to prevent establishment of the insect in the San Joaquin Valley of California, has been in effect for 10 years. Each year since initiation of the program, native males in widely varying numbers have been captured in the area. Further, it has been demonstrated that overwintering pink bollworm larvae can survive and emerge in the spring in the Bakersfield area. On the basis of this information plus indirect evidence of strong suppressive action during the regular growing season, it appears that the sterile releases can prevent establishment of active infestations, despite the knowledge that the released insects are inferior in several respects to native insects in the natural environment. In view of the low native moth populations as determined by pheromone trap data and the consistently high overall ratios of released to native moths each year, particularly during the early seasonal generations, very strong suppressive action due to the sterile males and sterile females is to be expected. This would be a valid assumption, even if the released moths were no more than 10 percent of normal competitiveness.

Research results to clearly demonstrate the role of sterile pink bollworm releases in suppressing established infestations of the insect have varied considerably. Much of the uncertainty of suppressive action is due to the infiltration of immigrant moths from distant heavily infested areas into poorly isolated experimental areas. The potential of the method and the economic importance of the pink bollworm justify the need to initiate appropriate large-scale field tests under isolated conditions to provide more definite information on the efficiency of moths of the type and quality now produced, and then undertake appropriate research to produce the best quality insect possible.

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SEX PHEROMONES OF THE PINK BOLLWORM AS TOOLS FOR SURVEY AND CONTROL

By H. M. Graham[1]

During studies on the mating behavior of pink bollworm moths, Ouye and Butt (*1962*)[2] found the female attracted the male for mating. They found this attraction was caused by an extremely potent chemical substance, or sex pheromone, emitted into the atmosphere by the female, and they were successful in extracting the attractive substance from the females. During the next few years, methylene chloride extracts of female moths were used to bait traps to survey for the pest and for various research studies.

Following this work, a search was started to find the chemical responsible for this attraction. In 1969, Keller et al. (*1969*) reported a chemical, *cis*-7-hexadecenyl, named hexalure, that attracted males similar to the extract of females, although it was not the natural pheromone. Because this chemical was more easily produced than the extract of females, which required the laborious rearing of insects, and was a powerful attractant for males, it supplanted the use of female extracts as an attractant.

Subsequently, Hummel et al. (*1973*) demonstrated the natural sex pheromone of the pink bollworm was a mixture of geometrical isomers of 7,11-hexadecadienyl acetate, which they called gossyplure. Their preliminary study showed a 1:1 ratio of *cis*-7, *cis*-11-hexadecadienyl acetate: *cis*-7-*trans*-11-hexadecadienyl acetate captured about 50 times more males than a similar amount of hexalure and 3 times more than 10 virgin females. These findings were confirmed by Bierl et al. (*1974*).

Sex pheromones might be used in two ways to aid in controlling infestations of the pink bollworm or other insects. One includes the use of traps baited with the pheromone to detect the spread of infestations or to determine population levels in an area as an aid in timing applications of insecticides. The second is the use of these substances to reduce pest populations.

Two methods have been suggested for using pheromones to reduce pest populations: Permeation of the atmosphere with the chemicals to inhibit communication between the sexes and prevent normal mating (Babson *1963*, Beroza and Jacobson *1963*, and Shorey et al. *1967*), or removal of males from the population

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 69.

by attracting them to pheromone sources, such as traps or insecticide-treated substrates, thus increasing the proportion of unmated females and infertile eggs (Knipling and McGuire *1966*). To effectively use either of these methods, the control measures must be initiated early in the season when pink bollworm populations are at their lowest point. The area to be treated should have relatively low overwintering populations or effective efforts must be made to reduce the overwintering populations by various control measures. Either of these techniques, if successful, would act specifically against the pink bollworm and avoid the adverse effects often encountered when a number of applications of chemical insecticides are used; however, neither technique may completely eliminate the need for some chemical applications.

Extensive studies, using the atmosphere permeation method, have been carried out, mainly in California, using hexalure or gossyplure. The results indicated control of the pink bollworm equivalent to applications of insecticides (Shorey et al. *1976*). In fields treated with these materials, the average pink bollworm infestations over a season were reduced 80 to 90 percent below those in nearby untreated fields. In a large test carried out in 1973, involving pheromone sources spaced 40 feet apart throughout cottonfields in the entire Coachella Valley of California, these workers reported infestations in bolls were delayed 3 to 4 weeks as compared with those in earlier years. The cost of this technique was similar to that of insecticidal control measures used during the preceding years.

Recent studies in other areas corroborated the results of the California work (Boness *1975*, Boness et al. *1977*, Brooks et al. *1979*). In replicated field trials in Arizona, SEA personnel of the Western Cotton Laboratory at Phoenix achieved a seasonal reduction in pink bollworm larvae of 68 percent in plots treated with aerial applications of gossyplure as compared with larvae in control plots (T. J. Henneberry, personal communication). The gossyplure was laminated between vinyl plastic layers that were cut into flakes. The flakes were suspended in an acrylic adhesive carrier and applied biweekly by aircraft at a rate of 46 g/ha of gossyplure per application.

Shorey et al. (*1976*) proposed an integrated control system using several methods to combat the pink bollworm. This system would include: (1) cultural measures to reduce the number of overwintering individuals; (2) the use of gossyplure to disrupt the premating communication between the sexes, thus delaying the buildup of populations during the growing season; and (3) insecticides to reduce populations late in the season in spots where they reached damaging numbers.

Although the pheromone has been registered for this method of suppressing pink bollworm populations and has been shown to be effective, it should be tried on a large scale for a sufficient period of time before it is recommended for general use.

Graham et al. (*1966*) attempted to suppress pink bollworm populations by using traps baited with the extract of females, but the attempt failed mainly because the trapped field was not isolated from other infested fields. Flint et al. (*1974*) captured 43 percent of labeled moths from overwintered larvae that they released early in the season in a 15-ha cottonfield containing 2.8 traps, each baited with 1 mg gossyplure/ha. Further studies were carried out on a farm containing 35.8 ha cotton (among other crops), using 12 to 50 traps/ha (Flint et

al. *1976*). Results of these studies, in which the proportion of the cotton acreage on which pink bollworm infestations reached the economic threshold of 10 percent of the bolls was 9 percent as compared with 45 to 100 percent during the preceding 3 years, suggested this method had some promise for pink bollworm control.

Huber et al. (*1979*) studied the use of a high density of traps (11/ha) baited with gossyplure to suppress pink bollworm populations in Arizona. In a large-scale trapping study in the Safford Valley, Ariz., during 1975-77, pink bollworm populations were much lower through the season than during the preceding 3 years when no trapping was carried out. Studies in Israel by Newmark et al. (*1975*) indicated that trapping combined with insecticide applications also showed promise as a method for controlling this pest. While there appears to be some promise in this method of suppressing pink bollworm populations, it should be studied more thoroughly before it is recommended for general use.

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ENTOMOPHAGOUS INSECTS ATTACKING THE PINK BOLLWORM

By C. G. Jackson[1]

INTRODUCTION

The pink bollworm, *Pectinophora gossypiella* (Saunders), because of its feeding habits, does not lend itself to effective biological control with available natural enemies as readily as do some other insect pests. Normally, it is exposed for only a small part of its immature life: as an egg (3 to 12 days), as a first-stage larva (about 1 day), as a mature larva searching for a place to pupate, and as an occasional pupa in trash beneath the plants.

The spring generation of larvae occurs before the first bolls are set and is forced to feed on squares and blooms. Those in the blooms are exposed to more predation and parasitism than later generations that feed inside bolls. There are no known parasites or predators that give complete control, but a number of native and introduced natural enemies have been shown to provide partial control.

NATIVE NATURAL ENEMIES

Several parasites native to North America have been recognized as attacking pink bollworms (Noble *1969*).[2] A few have parasitized a substantial portion of the pink bollworm populations in localized areas but none prevented the buildup of heavy infestations and subsequent damage. Most notable of these was *Bracon* (=Microbracon) *playnotae* (Cush) (Rude *1937*). No work has been reported on attempts to manipulate naturally occurring parasites to increase their effectiveness.

Only recently have studies been undertaken to determine the potential of native predators for control of pink bollworms. In southern Arizona, natural predation of eggs on cotton plants in the field was shown to be 33.3 and 72.2 percent after exposure periods of 24 and 48 hours, respectively (M. L. Lindsey,

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[2]The year in italic, when it follows the author's name, refers to Literature Cited, p. 74.

M.S. Thesis, University of Arizona, 1970). All the common predators in cottonfields in southern California, with the exception of spiders, are capable of feeding on pink bollworm eggs, and all can feed on first-stage larvae when confined with them (Orphanides et al. *1971*). In field cages, *Nabis americoferus* Carayon and *Geocoris pallens* Stål, at population levels that sometimes occur in the field, destroyed about one-half of the eggs present. *Chrysopa carnea* Stephens was also effective, but only at numbers far exceeding those that are found in field situations (Irwin et al. *1974*). Of all the predators studied, only the earwig, *Labidura riparia* (Pallas); spiders; the ground beetle, *Calasoma affine* Chaudoir; and the assassin bugs, *Sinea diadema* (F.) and *Zelus renardii* Kolenati, were capable of feeding on mature free larvae. Spiders and the ground beetle were eliminated from this list on cocooned larvae, and only earwig fed on pupae (Orphanides et al. *1971*).

Several attempts to monitor or manipulate movements of predator populations have been reported in southern Arizona (Bryan et al. *1976*, Fye *1971*, Fye and Carranza *1972*). Large populations of *Chrysopa carnea* and ladybird beetle, *Hippodamia convergens* (Guerin-Meneville), may develop on aphids in grain sorghum in the spring, but movement of those predators to cotton depends on the sorghum reaching maturity at the proper time.

INTRODUCED NATURAL ENEMIES

Very little work has been done with introduced predators of pink bollworms. Two species of *Chrysopa* from Pakistan and one from Florida, were released in pink bollworm-infested cotton in southern California, but there is no record of establishment by either species (Legner and Medved *1979*). Also, an assassin bug, *Coranus spiniscutis* Reuter, was imported from Pakistan and tested, but not released because a high mortality of the immature stages made it difficult to rear in large number. In addition, it was outdone in test by the native assassin bug, *Zelus renardii*, in southern Arizona (C. G. Jackson, unpublished data).

Much effort has gone into collecting, importing, rearing, and releasing foreign parasites. Early releases were made in southwestern Texas, Mexico, and Puerto Rico with parasites collected mostly in Africa, southern Europe, and Hawaii. In 1932-44 and 1953-55, 11 species of parasites were released in Texas, 8 species in Mexico, and 3 species in Puerto Rico (McGough and Noble *1955*, Noble and Hunt *1937*, Rude *1937*). Several of the parasites were recovered from pink bollworm-infested cotton bolls during the season in which they were liberated, but none was collected in successive seasons. Extensive use of insecticides and cultural control directed toward the pink bollworm were given as reasons the parasites did not become established.

More recent work with introduced parasites was done in Arizona (Bryan et al. *1973*, *1976*) and in California (Legner *1979*, Legner and Medved *1979*). Large scale releases of *Bracon kirkpatricki* (Wilkinson) and *Chelonus blackburni* Cameron were made in southern Arizona during 1971-74. In these tests, *B. kirkpatricki* showed promise for control of the spring generation of pink bollworms that occurs in blooms, but no evidence of overwintering was found. *Chelonus blackburni*, on the other hand, demonstrated an ability to overwinter, but cul-

tural controls against diapausing pink bollworm larvae were effective against the parasite as well (Fye and Jackson *1973*). Bioassays showed the insecticide combinations of ethyl parathion plus toxaphene (1.25 to 1.75 + 2.25 to 3.50 kg/ha) and methyl parathion plus toxaphene (1.14 + 4.55 kg/ha) at dosages recommended for pink bollworm control had effective residual action against both parasites for periods up to 2 weeks.[3]

Fourteen species of parasites were introduced into the low desert areas of southern California from 1969 to 1976 by entomologists at the University of California-Riverside. Those which provided some degree of control were *Bracon kirkpatricki*, *Chelonus blackburni*, *Chelonus* spp. near *curvimaculatis* Cameron from Ethiopia, and *Pristomerus hawaiiensis* Ashmead from Hawaii. In 1977, releases of *Chelonus blackburni*, a new species of *Chelonus* from northwestern Australia, and *Pristomerus hawaiiensis* near Parker, Ariz., provided a 70-percent reduction of infestations in green bolls. Of the three species, the northwestern Australian *Chelonus* appeared to be the most effective. Releases of promising parasites are continuing at the Parker site (Legner and Medved *1979*).

SUMMARY OF PAST WORK

Most of the past work with entomophagous insects (natural enemies) of pink bollworm has been concentrated on parasites collected in Pakistan, Africa, Europe, and Hawaii and subsequently released in the cotton-growing areas of southwestern United States. Several species of the genus *Chelonus* have demonstrated the ability to overwinter in this area and under proper conditions might become established and furnish a permanent, but partial, control measure; however, they overwinter in diapausing pink bollworms, and effective cultural control of the pests is also effective against the parasites. Other parasite species, especially the larval parasites *Bracon kirkpatricki* and *Pristomerus hawaiiensis* that have provided partial control, require mass rearing and release. Present rearing procedures require rearing of pink bollworm larvae or other larvae as hosts and are too costly for other than experimental releases. Native predators provide some measure of control, but it is difficult to determine the actual amount. This is because some are general feeders and attack the most abundant prey or prey that are most easily captured, whereas others prefer other prey and feed on pink bollworms only when they happen to find them. In both cases, predation on pink bollworms would depend on the number of pink bollworms present in a given area in relation to the numbers of other prey present in the same area.

DIRECTION OF FUTURE EFFORTS

Any biological control effect against pink bollworms must be one that is adaptable to an integrated program that includes minimal insecticide usage, for pink bollworm or other pests, and practical farming procedures. Few tests have

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[3] 3 lb ethyl parathion plus 6 lb toxaphene/gal at 0.33 to 0.5 gal/acre or 2 lb methyl parathion plus 8 lb toxaphene/gal at 0.5 gal/acre.

been conducted to determine the tolerances of beneficial insects to insecticides, but widespread usage of insecticides generally precludes effective biological control.

Several parasites and predators have demonstrated the ability to furnish partial control of pink bollworm populations. If útilized correctly, this partial control can be of value in delaying necessary insecticide applications. With the cost of insecticides and their application, and with the disruption of natural control of all potential pests, this postponement is of obvious value. Some emphasis should be given to studies of methods to conserve and manipulate populations of natural enemies. These methods include: (1) growing of alternate crops so that natural enemies have hosts or prey available between cotton-growing seasons or when the cotton is treated with insecticides, (2) spot usage of insecticides on an as-needed basis only and with insecticides that have the least effect on beneficial insects, and (3) use of kairomones and other chemicals that attract natural enemies to plants, hosts, or prey and that may be used to keep these enemies searching in a given area and thus increase their efficiency.

Some workers now believe that the pink bollworm originated in an area extending from northwestern Australia to Malaysia and Indonesia. Only a few places in this area have been searched for natural enemies of the pink bollworm. Future work should include such a search, especially in areas where the climate is similar to that in the cotton-growing regions of the Southwest.

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ENTOMOPATHOGENS FOR PINK BOLLWORM CONTROL

By M. R. Bell and T. J. Henneberry[1]

BACTERIA

Several early workers reported the isolation of pathogens from pink bollworms, *Pectinophora gossypiella* (Saunders), and attempts at using those isolates as control agents. In 1932, Metalnikov and Metalnikov (*18*)[2] isolated several species of bacteria from pink bollworm larvae. At least one of these isolates would kill pink bollworm larvae within 48 hours. Later, Metalnikov and Metalnikov (*19*) went on to test a bacterium, later identified as *Bacillus thuringiensis* Berliner, in field tests against several Lepidoptera, including the pink bollworm, and reported encouraging results. White and Noble (*26*) reported the isolation of a pathogenic species of *Bacillus* associated with pink bollworms in a laboratory culture; however, the species was described as nonsporulating and would not now be considered a *Bacillus*.

Although *B. thuringiensis* had been known since the first of the century, there was an awakened interest in its use as a potential control agent in the early 1950's. One important discovery which lead to a better understanding of the mode of action of *B. thuringiensis* was made by Hannay (*9*). He described the parasporal crystal and, more importantly, speculated that the inclusions were possibly associated with pathogenicity. This led to products that were standardized through bioassays in comparison with a standard, rather than on a spore basis, and resulted in more uniform virulence within test materials. Ignoffo (*10*, *11*) demonstrated that pink bollworm larvae were susceptible to intrahemocoelic injections of *B. thuringiensis* spores, determined quantitative criteria of LD and LT values, and indicated that expected temperatures and humidity under field conditions would be compatible with the use of this bacterium for control of pink bollworms.

Further testing showed that first-instar pink bollworm larvae were susceptible to a lactose dust formulation of this bacterium (*14*). Also, field cage tests in 1961 and 1962 demonstrated that mature larvae could be affected by incorporating *B. thuringiensis* into the soil. The results showed that treating the soil with the bacterium resulted in approximately a 40-percent reduction in pink bollworm moth emergence; however, the rates of application used to achieve this control were not economically feasible.

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[2] Italic numbers in parentheses refer to Literature Cited, p. 79.

Treating cotton in field cages with a commercial preparation of *B. thuringiensis* resulted in a significant decrease in the number of infested blooms, percentage bolls having mines, and the number of larvae in bolls (*5*). In untreated cotton, 80 percent of the bolls had larval mines compared with 10 percent in cottreated with 2 qt/acre of the formulated bacterium; however, these results were not reproducible in subsequent experiments (H. T. Dulmage, personal communication). Graves and Watson (*8*) also reported poor control of pink bollworms using another commercial preparation of *B. thuringiensis*. *B. thuringiensis var. kurstaki* (*alesti*) (coded: HD-1) was isolated in 1967 from black larvae that occurred in mass rearing containers of pink bollworms (*7*). Bioassays showed this isolate to be approximately 200 times more active against the pink bollworm, and several other hosts, than a typical commercial formulation.

Although methods for the feasible usage of *B. thuringiensis* to obtain subeconomic levels of control of pink bollworms have not yet been developed, this bacterium will have to be seriously considered in future studies concerning microbial control of this pest. This microbial agent is already registered for use on cotton against other pests and is presently manufactured in large amounts. Also, other isolates of this bacterium have been shown to be highly virulent against the pink bollworm. Commercial production of such isolates would not be difficult, as industrial methods for production are already known.

VIRUSES

Ignoffo and Adams (*12*) described a cytoplasmic polyhedrosis virus (CPV), *Smithiavirus pectinophorae*, found in pink bollworms from a laboratory culture. Feeding larvae on virus-treated diet resulted in reduced pupal weight and pupation rate as well as mortality of immatures. These authors noted that high doses of CPV would be required to obtain larval mortality comparable to other pathogens such as nuclear polyhedrosis virus (MPV) since the CPV induces a chronic disease. They noted that the debilitative effects of this disease, however, might be useful as a control agent.

Further descriptions of the effects of CPV on the pink bollworm were reported by Bullock et al. (*6*) and Bell and Kanavel (*2*). It was found that approximately 191 polyhedral inclusion bodies (PIB)/ml in diet would infect half the test larvae, whereas 172,000 PIB/ml would be required for an LD_{50}. Later, it was indicated that infection by CPV significantly affected the ability of pink bollworm larvae to remain in diapause (*1*). A field-cage test was conducted in which caged cotton was infested with adult pink bollworms (CPV infected vs. healthy) to determine if the disease would remain in a caged population in the field (M. R. Bell, unpublished data). The results indicated that there was no significant difference between the rates of increase in the populations. Also, CPV was not found in the overwintering larvae, indicating that the disease did not persist in the field.

Vail et al. (*25*) demonstrated that the nuclear polyhedrosis virus (NPV) isolated from the alfalfa looper, *Authographica californica* (Speyer), also infected pink bollworm larvae. This virus (ACNPV) was shown to have a wider host range than most of the known NPV's and also infected several other Lepidopteran pests of cotton (*23*, *24*). Field tests were conducted at Parker, Ariz.,

in 1973 and 1974 to evaluate the potential of ACNPV in pink bollworm control (*22*). These tests were designed to determine the numbers of larvae that would be infected by ACNPV (1.0×10^{12} PIB/acre per application), and the resulting effect on the population, when applied either in a bait formulation (*17*) or with a UV protectant (IMC Shade®). Also, Frego-bract cotton was evaluated because of the possiblity that it could affect the behavior of the pink bollworms and make the target sites more accessible to the virus spray. In those tests, weekly applications of this NPV did not reduce pink bollworm populations in any cotton variety. Larvae that were infected with ACNPV were found, but the infection rate was less than 1 percent based on 3,500 larvae examined.

FEEDING STIMULANTS TO ENHANCE THE EFFECTIVENSS OF VIRUSES AND BACTERIA

The effectiveness of applied microbial control agents, such as *B. thuringiensis* and the viruses, which must be ingested in order to infect the host, is seriously limited by the habits of the target insect. Internal feeders, such as leaf miners and borers, even though very susceptible to the pathogens in laboratory conditions, may almost totally escape infection in the field because their feeding site or habits protect them from consuming the pathogen. Such is partly true of the pink bollworm. Brazzel and Martin (*4*) demonstrated that green bolls were a favored oviposition site for pink bollworm females and that a high percentage of eggs on bolls was under the calyx. McLaughlin (*15*) showed that early in the season, and even after some bolls were present on cotton, the majority of pink bollworm eggs were deposited on plant parts other than bolls; however, the preferred oviposition site then shifted to bolls and under the calyx. He also found that even when the eggs were distributed at random on the plants, the newly hatched larvae would enter bolls or squares within about 40 min; thus, they would no longer be susceptible to the environment nor to applied pathogens.

While the larvae are exposed, the effectiveness of pathogens may be increased by formulating them with a feeding stimulant to increase ingestion by the larvae. Parrot et al. (*21*) showed that certain water extracts of cotton would elicit feeding responses by neonate pink bollworms. Laboratory and greenhouse studies then showed that greater numbers of pink bollworm larvae became infected when a virus was applied in a feeding-stimulant formulation (*2*).

Subsequent field tests demonstrated that the number of pink bollworm larvae in bolls was reduced (69 percent as compared with the control) when NPV from the alfalfa looper was applied to cotton in the feeding-stimulant formulation (*3*). Data indicated the treatment was more effective during the first part of the growing season than later in the season. Also, the formulation alone reduced the numbers of pink bollworm larvae in bolls (42 percent) apparently due to altered feeding behavior of newly hatched larvae. As in previous reports (*22*), the virus in aqueous suspension did not affect the population. The control obtained in this test was not deemed practical due to the quantity and cost of materials; however, data indicated an early season application might be useful in an integrated control program.

OTHER PATHOGENS

Other pathogens are known to infect the pink bollworm and can be considered potential control agents; however, few, if any, field tests have been conducted with these pathogens. Ignoffo and Garcia (*13*) found that pink bollworm larvae were susceptible to the protozoan, *Mattesia grandis* McLaughlin, isolated from the boll weevil (*16*) and to a microsporidian. Like the bacteria and viruses, these entomopathogens also must be ingested to infect the host.

One pathogen, shown to infect the pink bollworm, that does not have to be ingested is the nematode *Neoaplectana carpocapsae* Weisen (*20*). This parasite was shown to infect pink bollworm larvae and can move short distances to the host; however, since these parasites generally do best under moist conditions and apparently do not attack neonate larvae, they have not been evaluated as control agents since the probability of success is deemed to be low.

SUMMARY

In summary, control of pink bollworms with entomopathogens alone does not appear promising at this time. The habits of the larval stage of the pink bollworm tend to protect it from control by polyhedrosis viruses and bacteria--the pathogens given the best chance for commercial use with present technology. Some studies, however, have indicated that these pathogens may be of value in an integrated pest management system as an early season treatment when the use of chemical insecticides would be detrimental.

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